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**PROCEEDINGS**  
**OF THE**  
**ACADEMY OF SCIENCES**  
**OF THE**  
**UNITED PROVINCES OF AGRA AND OUDH**  
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PROCEEDINGS  
OF THE  
ACADEMY OF SCIENCES

(UNITED PROVINCES OF AGRA AND OUDH, INDIA)

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Part I ]

August 1934

[ Volume 4

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THE MATHEMATICAL THEORY OF A NEW RELATIVITY

BY SIR SHAH SULAIMAN,

CHIEF JUSTICE, HIGH COURT, ALLAHABAD

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CHAPTER I

A New Relativity

SECTION I

INTRODUCTORY

Newton assumed that gravitation had an instantaneous effect, howsoever distant the object might be. This implied that its velocity was infinite. He further assumed that the same law of gravitation applied between two bodies, whether they were at rest or in relative motion. Later observations showed that his law was inaccurate for moving bodies.

Einstein has given a slightly more accurate law, but at the complete sacrifice of the principles of Newton. Relativity denies the absoluteness of space, time and motion, but can hardly deny the absoluteness of angular motion or sudden change of motion.

"In the modern theory the question between Copernicus and his predecessors is merely one of convenience; all motion is

relative, and there is no difference between the two statements the earth rotates once a day and the heavens revolve round the earth once a day. The two mean exactly the same thing" (Bertrand Russell)<sup>1</sup>

But when a boy spins a top, does he give an absolute rotational motion to the top or does he set the entire universe revolving round the top in the opposite direction? Or again, when a motorist suddenly puts on the brakes, does he stop his car or does he push the whole universe on a backward path?

Relativity makes the velocity of light absolute, and although it is a known finite velocity (300,000 km per sec.), the properties of infinity are attributed to it; and no velocity, howsoever great, when added to it or subtracted from it, can ever make any difference

"A Beta particle shot off from Radium can move at more than 200,000 km. per sec., but the speed of light relative to an observer travelling with it is still 300,000 km per sec" (Eddington)<sup>2</sup>

It makes time and mass depend on velocity, and yet it is immaterial whether the body is approaching to or receding from the observer.

"If A and B were twin brothers, then B must be younger when he returns from his voyage than A. This is truly a strange deduction, which can, however, be eliminated by no artificial quibbling. We must put up with this" (Max Born)<sup>3</sup>

It makes length contract in the direction of motion, creating the paradox of a rotating wheel, where the rim contracts, but the spokes do not in the same exact proportion

Relativity does not only regard time as a fourth co-ordinate, but makes it a fourth dimension of space, and thereby gives to space a curvature and other properties, though still regarding it as a vacuum and not a medium like ether. It makes space finite, and yet makes its finite limit incapable of being reached except in infinite time, by making time itself slow down with distance, and ultimately become stationary. It extends the Pythagorean theorem to four dimensions and assumes that the square of the interval between two events is the difference between the square of the spacial dimension and the square of the distance travelled by light

"If you had been a ray of light, travelling round the solar system, starting from London at 10 a.m., reflected from Jupiter to



Saturn, and so on, until you were reflected back to Edinburgh and arrived there at 6-30 p m, you would judge that the journey had taken you exactly no time " (Russell)<sup>4</sup>

It assumes that all laws of nature must have an invariable form in vacuum only, and yet applies the principle to gravitational space. It has also introduced a cosmical force of repulsion between two bodies, which not only acts at a distance without any medium, but has its intensity incomprehensibly increasing as the distance between them increases, with the result that the whole universe must be exploding at a terrific rate. But the Galactic system, as Nature's favourite, is exempt from the operation of that law, for distant stars are not seen to be scattering away from one another at velocities proportional to the distances between them. Unfortunately for Relativity, at least five of the nebulae are approaching with rather high velocities, which are exceptionally well determined, and whose motions are not wholly explained by the rotation of the Galactic system.

"In the full formula there are no terms which under any reasonable conditions encourage motion towards the origin. It is, therefore, difficult to account for these motions even as exceptional phenomena." (Eddington)<sup>5</sup>

"The five approaching velocities are at least *partly* attributable to the use of an inappropriate standard of reference. . . the approaching velocities are *reduced* or disappear" (Eddington)<sup>6</sup>

But even if they disappear they would not give recessional velocities proportional to distances.

As relativity compels every body to keep its own separate and independent time, the problem of the interaction of more than two bodies moving simultaneously becomes insoluble.

"The existence of an electron contradicts the electromagnetic laws with which we have to work at present, so that from the present standpoint an electron at rest in no external field of force is a *miracle*. . . . An electron in an external field of force having the (derived) acceleration is precisely the *same miracle*." (Eddington)<sup>7</sup>

These apparently unconvincing assumptions remained unaccepted for many years, until Einstein's equations were believed to have been verified in three remarkable instances, *viz.*, (a) the deflection of light from a star when passing close to the Sun, (b) the displacement of the

Fraunhofer lines and (a) the advance of the perihelion of Mercury. But for such verifications it is doubtful whether relativity could have held its ground so long. In the absence of any better substitute, there has been no option but to accept it. But it is now established that the supposed verifications are not exact.

(a) According to Newton's theory, the deflection of light should be  $0' 87$ , according to Einstein, it should be  $1'' 75$ , but Freundlich and Klüber in 1931 found it to be  $2'' 24 \pm 0' 10$  if not more<sup>8</sup>

(b) The displacement of the blue light according to Einstein should be 0084, but it is only 0036, as observed by St. John<sup>9</sup>

The recent observation of Vyssotskiy<sup>10</sup> that the density of the Companion of Sirius is less, and therefore its radius larger than what was supposed, creates a similar discrepancy between Einstein's theoretical value and the observed value.

(c) Einstein's value for the advance of the perihelion is  $42'' 9$ , and this theoretical value had been found even before Relativity by Gerber<sup>11</sup> in 1902, but his method was different and his equation did not yield the value for the deflection of light. The calculated mean value based on observation comes to  $40'' 00$ <sup>12</sup>

If it can be shown that the ordinary principles of dynamics, when applied to moving bodies, themselves yield modified forms of equations, which as a first approximation reduce themselves to Newton's forms, and as a second approximation to Einstein's forms, the Newtonian mechanics would be restored to the eminent position it occupied before its dethronement by Relativity, and there would no longer be any absolute necessity to accept the extraordinary hypotheses on which Relativity is founded. If the theoretical values derived from the equations tally more exactly with the observed values, and the deflection of light were 26 times that under Newton's law, the displacement of the Fraunhofer lines were less than  $\frac{1}{2}$  of the value under Relativity, the theoretical value for the advance of the perihelion nearer to the observed value, and velocities of both recession and approach were permissible for the nebulae, the assumptions in Relativity would be proved to be wrong. It is submitted herein that such modified forms of equations can be obtained.

I must express my gratitude to Dr D.S. Kothari, M.Sc., Ph.D., Reader in Physics at the Delhi University, for his kindness in going through the manuscript and making valuable suggestions, and also to Mr. A N. Chatterji, M.Sc., who has kindly helped me in checking the mathematical processes and making calculations.

## SECTION II

## GRAVITATION BETWEEN TWO STATIONARY BODIES

1 In the Unified Theory of Physical Phenomena a new theory of gravitation based on internal action and not due to any extraneous force acting at a distance was put forward. The assumption was that light consists of material corpuscles called "radions" which are emitted from surfaces of bodies, and that there are still finer particles called "gravitons" which emanate from the entire mass, but are at present beyond the range of our perception. The rate of emanation of gravitons is dependent on the material density existing in the neighbourhood. It was shown that if the presence of matter retards emanations then the diminution in the losses of momenta from the side of a body facing another body as compared with the unaffected losses on the other side would result in a net difference of momentum in the direction of the influencing body, and would cause the influenced body to move towards it. This retardation of emanation from the side opposed to the moving gravitons can be interpreted as a stimulation of emanation in the direction of the moving gravitons as Einstein has assumed in the case of light. It was further shown that the apparent force between the two bodies must be proportional to their masses, and that the intensity of their mutual influence must vary inversely as the square of the distance between them, giving the Newtonian law

$$F = G \cdot \frac{M \cdot m}{R^2} \quad \dots \quad (2'1)$$

which holds between two *stationary* bodies only. This will be examined again mathematically in Chapter IV.

2 For the purposes of the matters dealt with in Chapter I, it is not even necessary to assume the existence of material gravitons. The results can be deduced equally well on the supposition that gravitation is the result of a wave propagation travelling with a finite velocity. For only portions of Chapters II and III the material aspects of radions and gravitons become necessary. It is only in Chapter IV when showing how both velocities of recession and approach become possible for nebulae that the theory of emission of gravitons becomes important.

## SECTION III

GRAVITATION ON A BODY MOVING RELATIVELY TO ANOTHER  
IN THE LINE OF CENTRES

1 It is submitted that Newton's law of gravitation which holds between two stationary bodies cannot apply to moving bodies. The apparent force of attraction between two bodies at rest is not the same when they are moving. Newton assumed that the effect of gravitation was instantaneous, but Laplace and several others after him assumed that it had a finite velocity. It is assumed herein that the velocity of gravitons is  $D$  which is nearly equal to  $C$ .

2 Let  $A$  and  $B$  be two small particles,  $A$  being supposed to be fixed and  $B$  moving relatively to it, and let the distance between them be  $r$ . If  $B$  also were stationary a graviton from  $A$  will reach  $B$  in time  $T_1 = \frac{r}{D}$ , when travelling

with velocity  $D$ . But if  $B$  moves towards  $B'$ , then by the time the graviton reaches the old position of  $B$ , the latter would have moved on to some intermediary position  $B'$ . Suppose the graviton overtakes  $B$  at the position  $B''$  at a distance  $\delta r$  from  $B$ ,  $\delta r$  is positive when measured away from  $A$  and negative when measured towards it. Then the time taken by the graviton to reach  $B''$  would be  $T_2 = \frac{r + \delta r}{D}$ . Then as successive gravitons reach  $B''$  the frequency of gravitons would be changed in the ratio

$$\frac{v_2}{v_1} = \frac{T_1}{T_2} = \frac{r}{r + \delta r} = \frac{1}{1 + \frac{\delta r}{r}} \quad \dots \quad (31)$$

This is the result of the motion of  $B$

## SECTION IV

1. Applying the principle of aberration of light to gravitation, a necessary result of the finiteness of the velocity is to shift forward the line of attraction towards the direction of motion. If  $\alpha$  be the angle of aberration;  $\theta$  the angle which the

direction of the earth's motion makes with the real direction of a star and  $v$  the velocity of the earth then  $\frac{v}{D} = \frac{\sin \alpha}{\sin \theta}$ . When the earth is moving at right angles to the line, then  $\theta = \frac{\pi}{2}$  and  $\frac{v}{D} = \sin \alpha$ , as also  $\tan \alpha$  when  $\alpha$  is small (4.1)

2 On the other hand, the change in the force of attraction due to the displacement of B to B' when it is overtaken by the gravitons is given by the ratio

$$\frac{\frac{\mu}{(r+\delta r)^2}}{\frac{\mu}{v^2}} = \left( \frac{1}{1+\frac{\delta r}{r}} \right)^2$$

It follows that the total change in the effect of gravitation due to both motion and displacement is given by the ratio

$$\left( \frac{1}{1+\frac{\delta r}{r}} \right)^2 \cdot \dots \dots \dots (4.2)$$

3 But as the times taken by the graviton to travel from A to B'' and by the particle to move from B to B'' are the same,  $\frac{r+\delta r}{D} = \frac{\delta r}{v}$  where  $v$  is the velocity of the particle B. From this we get

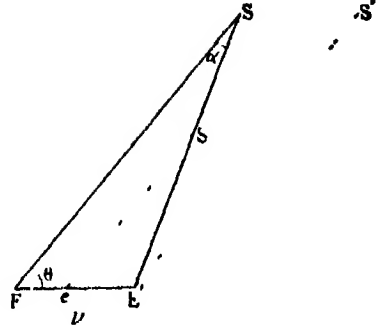
$$\left( \frac{1}{1+\frac{\delta r}{r}} \right) = \left( 1 - \frac{v}{D} \right)$$

The increased ratio of the change of gravitational force is therefore  $\left( 1 - \frac{v}{D} \right)^2$  which can be written in the more convenient form

$$\left( 1 - \frac{1}{D} \frac{dr}{dt} \right)^2 \cdot \dots \dots \dots (4.3)$$

where  $\frac{dr}{dt}$  will be positive when B is moving away from A, and negative when moving towards it.

4. It follows that when a planet is moving in its orbit round the sun, the effect of its radial velocity  $v$  is to change the effect of gravitation in the

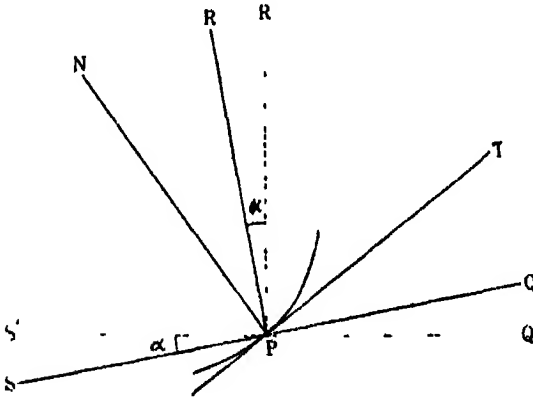


ratio  $\left(1 - \frac{v}{D}\right)^3$ , while the effect of its transverse velocity  $r \frac{d\theta}{dt}$  is to shift the direction of attraction forward by an angle  $\alpha$ , where  $\sin \alpha = \frac{1}{D} \frac{r d\theta}{dt}$  (4.4)

It is also obvious that although the apparent direction is altered the number of gravitons reaching it per unit time must remain the same

#### SECTION V PLANETARY ORBIT

- 1 Let P be the position of a planet in its orbit and  $(r, \theta)$  its polar coordinates with respect to the sun S. Let PS' be the shifted direction of the attraction of the sun, making an angle  $\alpha$  with PS. PR is the normal to SP and PR' is normal to S'P.



The accelerations due to the orbital motion along the radius vector and its normal are

$$\frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2$$

and  $\frac{1}{r} \frac{d}{dt} \left( r^2 \frac{d\theta}{dt} \right)$  respectively

But the whole force of attraction is directed along PS' and there is no force along the normal PR'. The effect of the Doppler principle as given in (4.3) is to change the effective force of gravitation to  $-\frac{\mu}{r^2} \left( 1 - \frac{v}{D} \right)^3$  where  $v$  is the velocity of the planet along S'P.

$$\begin{aligned} \text{But } v &= \frac{dr}{dt} \cos \alpha - \frac{r d\theta}{dt} \sin \alpha \\ &= \frac{dr}{dt} - \frac{1}{D} \left( r \frac{d\theta}{dt} \right)^2 \end{aligned}$$

since  $\cos \alpha \approx 1$  nearly, and  $\sin \alpha = \frac{v}{D} = \frac{1}{D} r \frac{d\theta}{dt}$

Resolving the accelerations along  $S'P$  and  $PR'$  we get

$$\left[ \frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2 \right] \cos \alpha - \left[ \frac{1}{r} \frac{d}{dt} \left( r^2 \frac{d\theta}{dt} \right) \right] \sin \alpha$$

$$= - \frac{\mu}{r^2} \left[ 1 - \frac{1}{D} \left\{ \frac{dr}{dt} - \frac{1}{D} \left( r \frac{d\theta}{dt} \right)^2 \right\} \right] \quad (5.2)$$

$$\text{and } \left[ \frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2 \right] \sin \alpha + \left[ \frac{1}{r} \frac{d}{dt} \left( r^2 \frac{d\theta}{dt} \right) \right] \cos \alpha = 0 \quad (5.3)$$

Multiplying (5.2) by  $-\sin \alpha$  and adding the result to (5.3) multiplied by  $\cos \alpha$ , we get

$$\frac{1}{r} \frac{d}{dt} \left( r^2 \frac{d\theta}{dt} \right) = \frac{\mu}{r^2} \left[ 1 - \frac{1}{D} \left\{ \frac{dr}{dt} - \frac{1}{D} \left( r \frac{d\theta}{dt} \right)^2 \right\} \right] \sin \alpha \quad (5.4)$$

Substituting  $\frac{1}{D} \left( r \frac{d\theta}{dt} \right)$  for  $\sin \alpha$  in (5.4) and neglecting terms of the second order on the right hand side after expansion we get,

$$\frac{d}{dt} \left( r^2 \frac{d\theta}{dt} \right) = \frac{\mu}{D} \frac{d\theta}{dt} \left[ 1 - \frac{3}{D} \left\{ \frac{dr}{dt} - \frac{1}{D} \left( r \frac{d\theta}{dt} \right)^2 \right\} \right]$$

$$= \frac{\mu}{D} \frac{d\theta}{dt} \text{ nearly, the other terms being small} \quad (5.41)$$

$$\text{Hence } r^2 \frac{d\theta}{dt} = h \left( 1 + \frac{\mu}{hD} \theta \right) \text{ where } h \text{ is a constant.}$$

$$= h (1 + k \theta) \text{ where } k = \frac{\mu}{hD} \quad (5.5)$$

Multiplying (5.2) by  $\cos \alpha$  and (5.3) by  $\sin \alpha$  and adding we get

$$\left[ \frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2 \right] = - \frac{\mu}{r^2} \cos \alpha \left[ 1 - \frac{1}{D} \left\{ \frac{dr}{dt} - \frac{1}{D} \left( r \frac{d\theta}{dt} \right)^2 \right\} \right] \quad (5.6)$$

$$\text{Hence } \frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2 = - \frac{\mu}{r^2} \left[ 1 - \frac{3}{D} \frac{dr}{dt} + \frac{3}{D^2} \left( r \frac{d\theta}{dt} \right)^2 \right] \text{ nearly} \quad (5.61)$$

This can be written in the form

$$\frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2 = - \frac{\mu}{r^2} - \frac{3\mu}{D^2} \frac{1}{r^2} \left( r^2 \frac{d\theta}{dt} \right)^2 + \frac{3\mu}{D} \frac{1}{r^2} \frac{dr}{dt}$$

$$= - \frac{\mu}{r^2} - \frac{3\mu}{D^2} \frac{h^2 (1 + k\theta)^2}{r^4} + \frac{3\mu}{D} \frac{1}{r^2} \frac{dr}{dt} \quad (5.7)$$

2 The above equation can be transformed into  $(u, \theta)$  form by putting  $r = \frac{1}{u}$  and therefore

$$\frac{dr}{dt} = -h(1+k\theta) \frac{du}{d\theta}$$

and 
$$\frac{d^2 r}{dt^2} = -h^2 u^2 (1+k\theta) \left[ (1+k\theta) \frac{d^2 u}{d\theta^2} + k \frac{du}{d\theta} \right]$$

Hence the equation (5.7) by substitution becomes

$$\begin{aligned} & -h^2 u^2 (1+k\theta) \left[ (1+k\theta) \frac{d^2 u}{d\theta^2} + k \frac{du}{d\theta} \right] - h^2 u^3 (1+k\theta)^2 \\ & = -(\mathcal{D}hk)u^2 - \frac{3(\mathcal{D}hk)}{\mathcal{D}^2} h^2 (1+k\theta)^2 u^4 - \frac{3(\mathcal{D}hk)}{\mathcal{D}} u^2 h (1+k\theta) \frac{du}{d\theta} \end{aligned}$$

Therefore 
$$\frac{d^2 u}{d\theta^2} + u = h^2 \frac{\mu}{(1+k\theta)^2} + \frac{3\mu}{\mathcal{D}^2} u^3 + \frac{2\mu}{\mathcal{D}h(1+k\theta)} \frac{du}{d\theta} \quad (5.8)$$

This can be written in the form

$$\begin{aligned} \frac{d^2 u}{d\theta^2} - 2 \frac{k}{(1+k\theta)} \frac{du}{d\theta} + u &= h^2 \frac{\mu}{(1+k\theta)^2} + \frac{3\mu}{\mathcal{D}^2} u^3 \\ \text{where } k &= \frac{\mu}{h\mathcal{D}} \end{aligned} \quad (5.9)$$

3. In order to appreciate the relative importance of the various terms in the equation (5.8) it is convenient to give the calculated values of the coefficients for a planet, say Mercury

$$\begin{aligned} \frac{\mu}{h^2} &= \frac{G M}{h^2} = \frac{6.67 \times 10^{-8} \times 1.98 \times 10^{33}}{(2.76 \times 10^{15})^2} = 1.73 \times 10^{-12} \\ \frac{2\mu k}{h^2} \theta &= 5.19 \times 10^{-17} \theta \\ \frac{3\mu}{\mathcal{D}^2} u^3 &= \frac{13.2 \times 10^{35} \times 3}{9 \times 10^{30} \times (387 \times 1.49 \times 10^{15})^2} = 1.32 \times 10^{-20} \\ \frac{2\mu}{\mathcal{D}h(1+k\theta)} \frac{du}{d\theta} &= \frac{2k}{(1+k\theta)} \frac{du}{d\theta} = - \frac{2 \times 1.5 \times 10^{-4}}{(2.76 \times 10^{15}) (1+k\theta)^2} \frac{dr}{dt} \\ &= -1.09 \times 10^{-28} \frac{dr}{dt}, \text{ (approximately)} \end{aligned}$$

For a whole revolution the total effect of the term containing  $\frac{dr}{dt}$  is very small because it changes its sign



4 The values of  $k$  for some of the other planets go on decreasing,—

Mercury	Venus	Earth	Mars
$1\ 62771 \times 10^{-4}$	$1\ 16531 \times 10^{-4}$	$99124 \times 10^{-4}$	$'80645 \times 10^{-4}$

## SECTION VI

## THE FIRST APPROXIMATION

The first approximation can be obtained at once from the equation (5 8) by treating  $k\theta$  as negligible, and ignoring the last two smallest terms. The equation then takes the form

$$\frac{d^2u}{d\theta^2} + u = \frac{\mu}{h^2} \quad \dots \dots (6\ 1)$$

which gives  $u = \frac{\mu}{h^2} [1 + e \cos (\theta - u)]$ , a perfect ellipse (6 2)

This is the well known Newton's form

We also get

$$r^2 \frac{d\theta}{dt} = h \quad (6\ 3)$$

$$h^2 = \mu l \quad \text{where } l = \frac{b^2}{a} \quad \dots (6\ 4)$$

$$v^2 = \frac{2\mu}{r} - \frac{1}{a} \quad \dots (6\ 5)$$

$$T^2 = \frac{4\pi^2}{\mu} a^3 \quad \dots (6\ 6)$$

## SECTION VII

## THE SECOND APPROXIMATION

The next approximation obviously is

$$\frac{d^2u}{d\theta^2} + u = \frac{\mu}{h^2(1 + k\theta)^2} \quad \dots \dots (7\ 1)$$

which gives

$$u = \frac{\mu}{h^2(1 + k\theta)^2} [1 + e \cos (\theta - u)] \quad (7\ 2)$$

This is an intermediary form

## SECTION VIII

## THE THIRD APPROXIMATION

1 The next approximation is obtained by neglecting  $k\theta$  and omitting the last term which is the smallest in (5.8). This is

$$\frac{d^2 u}{d\theta^2} + u = \frac{\mu}{h^2} + \frac{3\mu}{c^2} u^2$$

where  $c$  has been substituted for  $D$  in order that it may take Einstein's form. Its second approximate solution is

$$u = \frac{\mu}{h^2} \left[ 1 + e \cos(\theta - u) + \frac{3\mu^2}{c^2 h^2} e \theta \sin(\theta - u) \right] \quad (8.2)$$

This can be put in the form

$$u = \frac{\mu}{h^2} \left[ 1 + e \cos(\theta - u - \epsilon) \right] \quad (8.3)$$

where  $\epsilon = \frac{3\mu^2}{c^2 h^2} \theta$ .

2. It shows that the perihelion is advancing at the rate

$$\frac{\epsilon}{\theta} = \frac{3\mu^2}{c^2 h^2} \quad \dots \quad (8.4)$$

For one revolution, this gives

$$\epsilon = \frac{6\pi\mu^2}{c^2 h^2} = \frac{24\pi^2 a^3}{c^2 T^2 (1 - e^2)} \quad (8.5)$$

3. If the orbit be described by a particle of light,  $h$  becomes infinite in Relativity and so the equation becomes

$$\frac{d^2 u}{d\theta^2} + u = \frac{3\mu}{c^2} u^2 = \frac{3\mu}{c^2 R^2} \cos^2 \theta \quad (8.6)$$

By successive approximations, this gives

$$u = \frac{\cos^2 \theta}{R} + \frac{\mu}{c^2 R^2} (\cos^2 \theta + 2 \sin^2 \theta) \quad \dots \quad (8.7)$$

Putting  $x = r \cos \theta$  and  $y = r \sin \theta$  we get

$$x = R - \frac{\mu}{c^2 R} \frac{x^2 + 2y^2}{\sqrt{x^2 + y^2}} \quad (8.8)$$

Hence the angle between the asymptotes

$$x = R - \frac{\mu}{c^2 R} (1 + 2y) \quad (89)$$

This gives double the value for the deflection of light from a star passing close to the Sun, as compared to that given by the Newtonian Law

#### SECTION IX

##### THE FOURTH APPROXIMATION

The equation (8.1) may approximately be written as -

$$\frac{d^2 u}{d\theta^2} + u - \frac{3\mu}{D^2} u^2 = \frac{\mu}{h^2} (1 - 2h\theta) \quad \dots (9.1)$$

$$\text{Consider} \quad \frac{d^2 u}{d\theta^2} + u - \frac{3\mu}{D^2} u^2 = 0 \quad (9.2)$$

$$\text{Put } y = \frac{du}{d\theta} \text{ and therefore } \frac{d^2 u}{d\theta^2} = y \frac{dy}{du}$$

Substituting these values in (9.1) and multiplying by  $2 \frac{dy}{du}$  and integrating we get. -

$$y^2 = -u^2 + 2 \frac{\mu}{D^2} u^3 + A, \text{ where } A \text{ is a constant}$$

$$\text{Put } z = u - \frac{D^2}{6\mu} \text{ and therefore } \frac{dz}{d\theta} = \frac{du}{d\theta} \text{ and multiply by } \frac{2D^2}{\mu}$$

$$\text{Then } 4 \left( z + \frac{D^2}{6\mu} \right)^2 - \frac{2D^2}{\mu} \left( z + \frac{D^2}{6\mu} \right)^3 + \frac{2D^2}{\mu} A = \frac{2D^2}{\mu} y^2$$

$$\text{This gives } 4z^2 - \frac{4}{\mu^2} z - \left( \frac{2}{3} \frac{D^4}{\mu^3} - \frac{2D^2}{\mu} A \right) = \frac{2D^2}{\mu} y^2$$

But  $y = \frac{du}{d\theta} = \frac{dz}{d\theta}$  and hence substituting for  $y$ , taking the square root and integrating we get

$$\sqrt{\left( \frac{\mu}{2D^2} \right)} \theta = \int \frac{dz}{\sqrt{4z^2 - g_1 z - g_2}} + \text{constant}$$

$$\text{where } g_1 = \frac{4}{\mu^2} \text{ and } g_2 = \left( \frac{2}{3} \frac{D^4}{\mu^3} - \frac{2D^2}{\mu} A \right)$$

But by the definition of  $\wp$ -function of Weierstrass

$$\int_z^{\infty} \frac{dx}{\sqrt{4x^3 - g_2 x - g_3}} = \wp^{-1}(x)$$

Hence  $x = \wp \left\{ \frac{1}{D} \sqrt{\frac{\mu}{2}} (\beta - \theta) \right\}$  where  $\beta$  is a constant

Accordingly  $u = \frac{D^2}{6\mu} + \wp \left\{ -\frac{\sqrt{\mu}}{D\sqrt{2}} (\beta - \theta) \right\}$  is a solution of (9.2) (9.3)

Therefore the solution of (9.1) is

$$u = \frac{\mu}{h^2} (1 - 2k\theta) + \frac{D^2}{6\mu} + \wp \left\{ \frac{1}{D} \sqrt{\frac{\mu}{2}} (\beta - \theta) \right\}$$

where  $\wp(x)$  is known to be

$$= \frac{1}{x^2} + \sum_{m,n} \left\{ \frac{1}{(x - 2m\omega_1 - 2n\omega_2)^2} - \frac{1}{(2m\omega_1 + 2n\omega_2)^2} \right\} \quad (9.4)$$

See Whittaker and Watson<sup>13</sup> · Modern Analysis, p. 434, and G. Prasad's Introduction to the Theory of Elliptic Functions and Higher Transcendentals.<sup>14</sup>

The solution can be expressed in series by successive approximations.

2 It is submitted that the preceding alternative method is simpler than those adopted by Prof A. R. Forsyth in the Proceedings of the Royal Society of London<sup>15</sup> (Series A. Vol 97, (1920) p. 145), Prof. F. Morley in the American Journal of Mathematics<sup>16</sup> (Vol. 43 (1921) p. 29), and Prof James Pierpoint in the Bulletin of the American Mathematical Society<sup>17</sup> (1928) Vol 34 p, 582. These eminent mathematicians have taken the critical equation of Einstein's as their starting point and obtained the solution in elliptic functions of  $\left( \frac{du}{d\theta} \right)^2 + u^2 = \frac{c^2 - 1}{h^2} + \frac{2m}{h^2} u + 2m.u^2$  (9.5)

If we take the form (9.1) and neglect  $k$ ,

$$\frac{d^2 u}{d\theta^2} + u = \frac{\mu}{h^2} + \frac{3\mu}{D^2} u^2 \quad \dots \quad (9.6)$$

Multiplying by  $\frac{2du}{d\theta}$ , and integrating we get

$$\left( \frac{du}{d\theta} \right)^2 + u^2 = A + \frac{2\mu}{h^2} u + \frac{2\mu}{D^2} u^3 \quad \dots \quad (9.7)$$

where  $A$  is a constant determined by the initial conditions. This form

does not contain any apparent discrepancy as to the dimensions of its terms as (9.5) does

The two equations are identical, but the solution of (9.6) by approximation, which has only four terms, is simpler than that of (9.5) which has five terms. As shown in the preceding paragraph the simplicity is not lost even when  $\frac{\mu}{h^{\frac{1}{2}}}(1-2k\theta)$  is put in place of  $\frac{\mu}{h^{\frac{1}{2}}}$ .

3. If we multiply (9.2) by  $2 \frac{du}{d\theta}$  and integrate we get

$$\left(\frac{du}{d\theta}\right)^2 = \frac{2\mu}{D^2} u^3 - u^2 + B$$

Let  $\alpha$ ,  $\beta$  and  $\gamma$  be the three roots of  $u^3 - \frac{D^2}{2\mu} u^2 + B = 0 = (u - \alpha)(u - \beta)(u - \gamma)$

$$= u^3 - (\alpha + \beta + \gamma)u^2 + (\alpha\beta + \beta\gamma + \gamma\alpha)u - \alpha\beta\gamma$$

And so 
$$\alpha + \beta + \gamma = \frac{D^2}{2\mu}$$

$$\alpha\beta + \beta\gamma + \gamma\alpha = 0$$

$$\text{and } \alpha\beta\gamma = -B$$

From these we get 
$$\alpha + \beta - \frac{\beta}{\alpha\beta} = \frac{D^2}{2\mu}$$

$$\text{and } \alpha^2\beta^2 = (\alpha + \beta) \quad B$$

Thus when B is known the roots can be determined

## SECTION X

### THE FIFTH APPROXIMATION

1 As the term  $\frac{2\mu k}{h^{\frac{1}{2}}} \theta$  is comparable to  $\frac{3\mu}{D^2} u^2$ , the third approximation which gave Einstein's form after neglecting  $\frac{2\mu k}{h^{\frac{1}{2}}} \theta$  was really not quite correct. The approximation should be:—

$$\frac{d^2 u}{d\theta^2} + u = \frac{\mu}{h^{\frac{1}{2}}(1+k\theta)^2} + \frac{3\mu}{D^2} u^2 \quad \dots \quad (10.1)$$

A rough solution of this can be obtained easily by putting  $h(1+k\theta)=H$  and treating the latter temporarily as a constant. For small values of  $k\theta$ , we get

$$\frac{d^2 u}{d\theta^2} + u = \frac{\mu}{H^2} + \frac{3\mu}{D^2} u^2$$

As in Section VIII, this gives

$$u = \frac{\mu}{H^2} [1 + e \cos(\theta - \omega - \varepsilon)] \quad \text{where } \varepsilon = \frac{3\mu^2}{D^2 H^2} \theta$$

Re-instating  $h$  we get roughly

$$u = \frac{\mu}{h^2(1+k\theta)^2} [1 + e \cos(\theta - \omega - \varepsilon)]$$

$$\text{where } \varepsilon = \frac{3\mu^2}{D^2 h^2(1+k\theta)^2} \quad (10.2)$$

Hence so long as  $k\theta$  remains small, the value of the advance of the perihelion is given by

$$\varepsilon = \frac{12\pi^2 a^2}{c^2 T^2 (1-e^2)} \frac{\theta}{(1+k\theta)^2} \quad (10.3)$$

2. Similarly if we put  $h(1+k\theta)$  in place of  $h$  we can obtain an approximate value for the advance of the perihelion from (8.4) and (8.5) for one revolution as

$$\varepsilon = \frac{3\mu^2}{D^2 h^2(1+2\pi k)^2} \quad (10.4)$$

$$= \frac{24\pi^3 a^2}{D^2 T^2 (1-e^2)(1+2\pi k)^2} \quad (10.5)$$

$$\text{where } k = \frac{GM}{hD}$$

## SECTION XI

### THE SIXTH APPROXIMATION

The next approximation is the equation (5.9)

$$\frac{d^2 u}{d\theta^2} - \frac{2k}{(1+k\theta)} \frac{du}{d\theta} + u = \frac{\mu}{h^2(1+k\theta)^2} + \frac{3\mu}{D^2} u^2.$$

$$(1) \quad \text{Consider first} \quad \frac{d^2 u}{d\theta^2} - 2k \frac{du}{d\theta} + u = 0 \quad (11.1)$$

Trying  $u = A e^{\lambda \theta}$  we must have  $\lambda^2 - 2k\lambda + 1 = 0$

$$\lambda = k \pm \sqrt{1 - k^2} \text{ since } k < 1$$

Hence  $u = A e^{k\theta} (e^{\pm \sqrt{1 - k^2} \theta} + e^{\mp \sqrt{1 - k^2} \theta})$

$$= 2A e^{k\theta} \cos(\sqrt{1 - k^2} \theta)$$

Similarly another solution is  $u = 2B e^{k\theta} \sin(\sqrt{1 - k^2} \theta)$

Hence neglecting  $k^2$  the solution can be put in the form

$$u = \frac{\mu}{h^2} E e^{k\theta} \cos(\theta - \omega) \quad (11.2)$$

(2) By operating with  $(D^2 - 2kD + 1)$  on  $\frac{\mu}{h^2} (1 - 2k\theta)$

it is found that the solution of

$$\frac{d^2 u}{d\theta^2} - 2k \frac{du}{d\theta} + u = \frac{\mu}{h^2} (1 - 2k\theta) \quad (11.3)$$

$$\text{is } u = \frac{\mu}{h^2} (1 - 2k\theta) + \frac{\mu}{h^2} E e^{k\theta} \cos(\theta - \omega) \quad \dots \quad (11.4)$$

(3) Next consider

$$\frac{d^2 u}{d\theta^2} - 2 \frac{h}{1 + k\theta} \frac{du}{d\theta} + u = 0 \quad \dots \quad (11.5)$$

Try  $u = e^{k\theta(1 - k\theta)} \cos(\theta - \omega)$ , as  $(1 - k\theta) = \frac{1}{1 + k\theta}$  nearly

It will be found that in the coefficients of the terms containing  $\cos(\theta - \omega)$  and  $\sin(\theta - \omega)$ , neither any number nor  $k$  but only  $k^2$  occurs, which is negligible. So the equation is satisfied approximately

Hence a solution of (11.5) is

$$u = \frac{\mu}{h^2} E e^{1 + k\theta} \cos(\theta - \omega) \quad (11.6)$$

which gives the complementary integral

(4) By operating with  $(D^2 - 2kD + 1)$  on  $\frac{\mu}{h^2(1 + k\theta)^2}$  and neglecting smaller terms, it will be found that an approximate solution of

$$\frac{d^2 u}{d\theta^2} - 2 \frac{k}{(1 + k\theta)} \frac{du}{d\theta} + u = \frac{\mu}{h^2(1 + k\theta)^2} \quad \dots \quad (11.7)$$

$$\text{is } u = \frac{\mu}{h^2(1 + k\theta)^2} + \frac{\mu}{h^2} E e^{1 + k\theta} \cos(\theta - \omega), \quad \dots \quad (11.8)$$

so long as  $k\theta$  does not become large

(5) Substituting the approximate value (11.8) of  $u$  in the equation quoted above as the sixth approximation we get

$$\begin{aligned} \frac{d^2 u}{d\theta^2} - \frac{2k}{1+k\theta} \frac{du}{d\theta} + u &= \frac{\mu}{h^2(1+k\theta)^2} + \frac{3\mu}{D^2} \frac{\mu^2}{h^2(1+k\theta)^4} \\ &+ \frac{3\mu}{D^2} \frac{2\mu^2}{h^2} E \frac{e^{\frac{k\theta}{1+k\theta}}}{(1+k\theta)^2} \cos(\theta-\omega) \\ &+ \frac{3\mu}{D^2} \frac{\mu^2}{h^4} E^2 e^{\frac{2k\theta}{1+k\theta}} \cos^2(\theta-\omega) \end{aligned}$$

The second term on the right hand side is always too small as compared to the first and can be neglected. The fourth term is also very small compared to the third, and the period of  $\cos^2(\theta-\omega) = \frac{1+\cos 2(\theta-\omega)}{2}$  does not correspond with that of  $\cos(\theta-\omega)$ , hence this also is negligible. Only the third term produces a continually increasing resonance. So that

$$\frac{d^2 u}{d\theta^2} - \frac{2k}{1+k\theta} \frac{du}{d\theta} + u = \frac{\mu}{h^2(1+k\theta)^2} + \frac{6\mu^3 E}{D^2 h^4 (1+k\theta)^2} e^{\frac{k\theta}{1+k\theta}} \cos(\theta-\omega) \quad (11.9)$$

(6) As  $\frac{e^{\frac{k\theta}{1+k\theta}}}{(1+k\theta)} = \frac{1}{(1+k\theta)}$  nearly, it is convenient to consider

$$\frac{d^2 u}{d\theta^2} - 2k \frac{du}{d\theta} + u = A \frac{\cos \theta}{1+k\theta} \quad (11.10)$$

$$\text{By trying } u = \frac{1}{2} A \frac{\theta \sin \theta}{1+k\theta} \quad (11.11)$$

we find that —

$$\frac{d^2 u}{d\theta^2} - 2k \frac{du}{d\theta} + u = A \frac{\cos \theta}{1+k\theta} - 2A (\sin \theta + \theta \cos \theta) k.$$

If  $A = \frac{6\mu^3 E}{D^2 h^4}$  and  $k$  is of the order  $10^{-4}$ , the last term is negligible.

Hence (11.11) is an approximate solution of (11.10)

(7) Now as a particular solution of (11.10) is (11.11), a term of the solution of (5.9) is known. Adding the term to the complementary integral, we obtain from (11.9) and (11.6),

$$\begin{aligned} u &= \frac{\mu}{h^2(1+k\theta)^2} + \frac{\mu}{h^2} E e^{\frac{k\theta}{1+k\theta}} \cos(\theta-\omega) + \frac{3\mu^3}{D^2 h^4} E \frac{e^{\frac{k\theta}{1+k\theta}}}{(1+k\theta)^2} \theta \sin(\theta-\omega) \\ &\text{approximately.} \quad \dots \quad (11.12) \end{aligned}$$



This can be written in the form

$$u = \frac{\mu}{h^2 (1+k\theta)^2} \left[ 1 + E (1+k\theta)^2 e^{1+\frac{k\theta}{1+k\theta}} \cos (\theta - \omega - \varepsilon) \right]$$

$$\text{where } \varepsilon = \frac{3\mu^2}{D^2 h^2} \frac{\theta}{(1+k\theta)^2} \quad (11.13)$$

$$= 3 \left( \frac{k}{1+k\theta} \right)^2 \theta$$

(8) This solution can be verified by differentiation. When  $k^2$  is neglected,

$$u = \frac{\mu}{h^2 (1+k\theta)^2} \left[ 1 + E (1+k\theta)^2 e^{1+k\theta} \cos (\theta - \omega - \varepsilon) \right]$$

$$= \frac{\mu}{h^2} (1-2k\theta) \left[ 1 + E (1+2k\theta) (1+k\theta) \cos (\theta - \omega - \varepsilon) \right]$$

$$= \frac{\mu}{h^2} \left[ 1 + E \cos (\theta - \omega - \varepsilon) - 2k\theta + E k\theta \cos (\theta - \omega - \varepsilon) \right]$$

$$\frac{du}{d\theta} = \frac{\mu}{h^2} \left[ -E \sin (\theta - \omega - \varepsilon) - 2k + E k \cos (\theta - \omega - \varepsilon) \right. \\ \left. - E k\theta \sin (\theta - \omega - \varepsilon) \right]$$

$$\frac{d^2 u}{d\theta^2} = \frac{\mu}{h^2} \left[ -E \cos (\theta - \omega - \varepsilon) - 2E k \sin (\theta - \omega - \varepsilon) \right. \\ \left. - E k\theta \cos (\theta - \omega - \varepsilon) \right]$$

Hence

$$\frac{d^2 u}{d\theta^2} - 2 \frac{k}{1+k\theta} \frac{du}{d\theta} + u$$

$$= \frac{\mu}{h^2} \left[ -E \cos (\theta - \omega - \varepsilon) - 2E k \sin (\theta - \omega - \varepsilon) - E k\theta \cos (\theta - \omega - \varepsilon) \right. \\ \left. + 1 + E \cos (\theta - \omega - \varepsilon) - 2k\theta + E k\theta \cos (\theta - \omega - \varepsilon) \right. \\ \left. + 2k E \sin (\theta - \omega - \varepsilon) \right]$$

$$= \frac{\mu}{h^2} (1-2k\theta) = \frac{\mu}{h^2 (1+k\theta)^2} \text{ (approximately)}$$

The solution is therefore true up to the order  $\frac{\mu}{h^2}$ ,  $k = \frac{\mu^2}{h^2 D}$ .

(9) It is easily seen that if we take

$$u = h^{\frac{1}{2}} \frac{\mu}{(1+k\theta)^{\frac{3}{2}}} \left[ 1 + F_1 (1+k\theta)^n e^{\frac{k\theta}{1+k\theta}} \cos(\theta - \omega - \varepsilon) \right]$$

no other power will satisfy the differential equation except  $n=2$ .

## SECTION XII

### THE SEVENTH APPROXIMATION

In the new theory, the equations of motion are (5.7) and (5.41), viz,

$$\frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2 = -\frac{\mu}{r^2} - \frac{3\mu h^2}{D^2 r^4} + \frac{3\mu}{D} \frac{1}{r^3} \frac{dr}{dt} \text{ nearly}$$

$$\text{and } \frac{1}{r} \frac{d}{dt} \left( r^2 \frac{d\theta}{dt} \right) = \frac{\mu}{D} \frac{1}{r} \frac{d\theta}{dt}$$

From W. H. Besant's Dynamics,<sup>14</sup> Arts 160-161 we get the changes in the elements of Newton's ellipse, for which  $r^2 \frac{d\theta}{dt} = h$

$$1 \text{ For a small radial force } \delta a = f \delta t \quad 2e \sin \theta \sqrt{\frac{a^3}{\mu(1-e^2)}}$$

$$(1) \text{ If } f_1 = -\frac{3\mu h^2}{D^2} \frac{1}{r^4} \text{ nearly}$$

$$\delta a_1 = -\frac{3\mu h^2}{D^2} 2e \sqrt{\frac{a^3}{\mu(1-e^2)}} \frac{\sin \theta}{r^4} dt$$

$$\text{But } \int_0^{2\pi} \frac{\sin \theta dt}{r^4} = \int_0^{2\pi} \frac{\sin \theta}{r^4} \cdot \frac{r^2 d\theta}{h} = \frac{1}{h} \int_0^{2\pi} \frac{\sin \theta d\theta}{r^2}$$

$$= \frac{1}{h} \int_0^{2\pi} \sin \theta \frac{\mu^2}{h^4} (1 + e \cos \theta)^2 d\theta$$

$$= \frac{\mu^2}{h^6} \int_0^{2\pi} \sin \theta (1 + e \cos \theta)^2 d\theta = 0$$

Hence for one revolution  $\Delta a_1 = 0$ .

.. (12.1)

$$(2) \text{ If } f_2 = \frac{3\mu}{D} \frac{1}{r^2} \frac{dr}{dt} \quad \text{and} \quad -\frac{dr}{r^2} = -\frac{\mu}{h^2} e \sin \theta d\theta.$$

$$\begin{aligned} \delta a_2 &= \frac{3\mu}{D} \frac{1}{r^2} \frac{dr}{dt} dt = 2e \sin \theta \sqrt{\frac{a^3}{\mu(1-e^2)}} \\ &= \frac{e^2 \mu^2}{D h^2} \sqrt{\frac{a^3}{\mu(1-e^2)}} \sin^2 \theta d\theta \end{aligned}$$

$$\text{But } \int_0^{2\pi} \sin^2 \theta d\theta = \pi$$

$$\begin{aligned} \text{For one revolution } \Delta a_2 &= \frac{6\pi e^2 \mu^2}{D h^2} \sqrt{\frac{a^3}{\mu(1-e^2)}} \\ &= \frac{6\pi e^2 \mu^2 a^2}{D h^2} \end{aligned} \quad (12.2)$$

$$\text{For a small transverse force} \quad \delta a = f \delta t 2 \sqrt{\frac{a^3}{\mu(1-e^2)}} \left\{ 1 + e \cos \theta \right\}$$

$$(3) \text{ If } f_1 = \frac{\mu}{D} \frac{1}{r} \frac{d\theta}{dt}$$

$$\begin{aligned} \delta a_1 &= \frac{2\mu}{D} \sqrt{\frac{a^3}{\mu(1-e^2)}} \frac{\mu}{h^2} (1 + e \cos \theta)^2 \frac{d\theta}{dt} dt \\ &= \frac{2\mu^2}{D h^2} a^2 (1 + 2e \cos \theta + e^2 \cos^2 \theta) d\theta \end{aligned}$$

$$\text{But } \int_0^{2\pi} (1 + 2e \cos \theta + e^2 \cos^2 \theta) d\theta = \pi(2 + e^2)$$

$$\Delta a_3 = \frac{2\pi \mu^2 a^2 (2 + e^2)}{D h^2} \quad \dots \quad (12'3)$$

$$\begin{aligned} \text{Hence } \Delta a &= \Delta a_1 + \Delta a_2 + \Delta a_3 \\ &= \frac{4\pi \mu^2 a^2}{D h^2} (2e^2 + 1) \end{aligned} \quad (12.4)$$

$$2 \text{ For a small radial force } \delta e = f \delta t \sin \theta \sqrt{\frac{a(1-e^2)}{\mu}}$$

(1) If  $f_1 = -\frac{3\mu h^2}{D^2} \frac{1}{r^4}$ , then it is easily seen as in the preceding paragraph that

$$\Delta e_1 = 0 \quad (12'5)$$

$$(2) \text{ If } f_2 = -\frac{3\mu}{D} \frac{1}{r^2} \frac{dr}{dt}, \text{ then as } -\frac{dr}{r^2} = -\frac{\mu}{h^2} e \sin \theta d\theta$$

$$\begin{aligned} \delta e_2 &= -\frac{3\mu}{D r^2} \frac{dr}{dt} \sin \theta \sqrt{\frac{a(1-e^2)}{\mu}} dt \\ &= -\frac{3e\mu^2}{D h^2} \sqrt{\frac{a(1-e^2)}{\mu}} \sin^2 \theta d\theta \end{aligned}$$

$$\text{But } \int_0^{2\pi} \sin^2 \theta d\theta = \pi$$

$$\Delta e_2 = \frac{3\pi e\mu^2}{D h^2} \sqrt{\frac{a(1-e^2)}{\mu}} = \frac{3\pi e\mu}{D h} \quad (12.6)$$

For a small transverse force

$$\delta e = f \delta t \sqrt{\frac{a(1-e^2)}{\mu}} \left\{ \cos \theta + \frac{e + \cos \theta}{1 + e \cos \theta} \right\}$$

$$(3) \text{ If } f_3 = \frac{\mu}{D} \frac{1}{r} \frac{d\theta}{dt}, \text{ then}$$

$$\delta e_3 = \frac{\mu}{D} \sqrt{\frac{a(1-e^2)}{\mu}} \frac{\mu}{h^2} \left\{ e + 2 \cos \theta + e \cos^2 \theta \right\} d\theta$$

$$\text{But } \int_0^{2\pi} (e + 2 \cos \theta + e \cos^2 \theta) d\theta = 3\pi e$$

$$\Delta e_3 = 3\pi e \frac{\mu^2}{D h^2} \sqrt{\frac{a(1-e^2)}{\mu}} = 3\pi e \frac{\mu}{D h} \quad (12.7)$$

$$\text{Hence } \Delta e = \Delta e_1 + \Delta e_2 + \Delta e_3 = 6\pi e \frac{\mu}{D h} \quad (12.8)$$

$$3 \text{ For a small radial force } \delta \omega = -f \delta t \frac{\cos \theta}{e} \sqrt{\frac{a(1-e^2)}{\mu}}$$

$$(1) \text{ If } f_1 = -\frac{3\mu h^2}{D^2} \frac{1}{r^4}$$

$$\begin{aligned} \delta \omega_1 &= \frac{3\mu h^2}{D^2 e} \sqrt{\frac{a(1-e^2)}{\mu}} \frac{\cos \theta}{r^4} dt \\ &= \frac{3\mu h^2}{D^2 e} \sqrt{\frac{a(1-e^2)}{\mu}} \frac{\cos \theta}{h} \frac{\mu^2}{h^4} (1 + e \cos \theta)^2 d\theta. \end{aligned}$$

$$\text{But } \int_0^{2\pi} \cos \theta (1 + e \cos \theta)^2 = 2\pi e$$

$$\begin{aligned} \Delta \bar{\omega}_1 &= \frac{3\mu}{D^3 e} \sqrt{\frac{a(1-e^2)}{\mu}} \frac{\mu^2}{h^5} 2\pi e \\ &= \frac{6\pi \mu^2}{D^4 h^5} \sqrt{\frac{a(1-e^2)}{\mu}} = \frac{6\pi \mu^2}{D^3 h^5} \quad \dots \quad (12.9) \end{aligned}$$

$$(2) \text{ If } f_2 = \frac{3\mu}{D} \frac{1}{r^2} \frac{dr}{dt}$$

$$\begin{aligned} \delta \bar{\omega}_2 &= - \frac{3\mu}{D} \frac{1}{r^2} \frac{dr}{dt} \cdot \frac{\cos \theta}{e} \sqrt{\frac{a(1-e^2)}{\mu}} dt \\ &= - \frac{3\mu}{D} \frac{\mu}{h^2} e \sin \theta d\theta \cdot \frac{\cos \theta}{e} \sqrt{\frac{a(1-e^2)}{\mu}} \end{aligned}$$

$$\text{But } \int_0^{2\pi} \sin \theta \cos \theta d\theta = 0$$

$$\therefore \Delta \bar{\omega}_2 = 0 \quad (12.10)$$

*For a small transverse force*

$$\delta \bar{\omega} = f \delta t \frac{\sin \theta}{e} \sqrt{\frac{a(1-e^2)}{\mu}} \left( \frac{2 + e \cos \theta}{1 + e \cos \theta} \right)$$

$$(3) \text{ If } f_3 = \frac{\mu}{D} \frac{1}{r} \frac{d\theta}{dt}$$

$$\begin{aligned} \delta \bar{\omega}_3 &= \frac{\mu}{D} \frac{1}{r} \frac{d\theta}{dt} \frac{\sin \theta}{e} \sqrt{\frac{a(1-e^2)}{\mu}} \left( \frac{2 + e \cos \theta}{1 + e \cos \theta} \right) dt \\ &= \frac{\mu}{eD} \sqrt{\frac{a(1-e^2)}{\mu}} \frac{\mu}{h^2} (2 + e \cos \theta) \sin \theta d\theta \end{aligned}$$

$$\text{But } \int_0^{2\pi} \sin \theta (2 + e \cos \theta) d\theta = 0$$

$$\therefore \Delta \bar{\omega}_3 = 0 \quad (12.11)$$

**Hence**

$$\begin{aligned} \Delta \bar{\omega} &= \Delta \bar{\omega}_1 + \Delta \bar{\omega}_2 + \Delta \bar{\omega}_3 \\ &= \frac{6\pi \mu^2}{D^3 h^5} \text{ (for one revolution)} \end{aligned} \quad (12.12)$$

$$\text{From (8.5) this } = \frac{24\pi^3 a^3}{D^3 T^3 (1-e^2)} \quad \dots \quad (12.13)$$

4 (1) The orbit of the planet which is actually observed has the elements

$$a' = (a + \Delta a)$$

$$\text{and } e' = (e + \Delta e)$$

These therefore show no variations

(2) But the rotation of the perihelion is given by

$$\Delta \bar{\omega} = \frac{6\pi\mu^2}{D^2 h^2} \text{ which is observed}$$

5 The other terms in (5.61) which have been neglected produce no appreciable effect on the advance of the perihelion  $\Delta\omega$ , for three of the terms are zero, and two of them are of the order  $10^{-17}$  and  $10^{-16}$  respectively, which are both negligible. Similarly the effect of the other terms in (5.4) which have been neglected is negligible.

The method of treating the disturbed elliptic motion as being due to small additional forces which has been followed in this Section is not known to have been adopted previously.

## CHAPTER II

### Applications of the New Theory

#### SECTION I

#### THE ADVANCE OF THE PERIHELION

1 From the equation (11.13) the advance of the perihelion is given by

$$\epsilon = \frac{3\mu^2}{D^2 h^2} \frac{\theta}{(1+k\theta)^2} \text{ where } k = \frac{G}{h} \frac{M}{D} \text{ and}$$

for one revolution this gives —

$$\epsilon = \frac{6\pi\mu^2}{D^2 h^2} \frac{1}{(1+2\pi k)^2}, \quad k\theta \text{ being small.} \quad (13'1)$$

An equivalent formula from (8.5) is

$$\epsilon = \frac{24}{c^2 T^2} \frac{\pi^2 a^3}{(1-e^2)} \frac{1}{(1+2\pi k)^2} \text{ for one revolution ..} \quad (13.2)$$

Leverrier in 1859 and Newcomb in 1895 calculated the advance of the perihelion. The observed advance of the orbit is about 574" per century, and the calculated perturbations produced by all the known planets, on certain assumptions amount to about 532", leaving an excess of 42" per century. But the mean value<sup>12</sup> comes to 40" 00 ± 1" 16. The method of calculating the perturbations will be examined in Chapter III.

## SECTION II

## THE DEFLECTION OF LIGHT

1 If light be regarded as a material particle its motion will be governed by the same equations. But for light  $h$  and therefore  $h(1 + k\theta)$  is very large. Hence the equation (5.8) reduces to —

$$\frac{d^2 u}{d\theta^2} + u = \frac{3\mu}{D^2} u^2 \text{ as a first approximation.} \quad (11.1)$$

This is the same as (8.6)

Accordingly, as in Section VIII, the rays of light from a star when passing close to the Sun should as a first approximation be deflected by an angle  $\frac{4\mu}{R}$  which is double of that given by Newton's law

2	The value on Newton's Theory corresponds to	0" 87
	" " " Einstein's " "	1" 745
	The observed value at Sobral <sup>19</sup> (1919) was	1' 98 ± 0" 12
	The corrected value for Sobral (Hopmann <sup>20</sup> ) is	2' 16
	The American Expedition <sup>21</sup> (1922) after correction is	2' 30
	The observed values at Takengon, North Sumatra (1929) are	
	(Freundlich and Kluber) <sup>22</sup> minimum	1" 97
	maximum	2" 87
	mean	2' 24 ± 0" 10

The corrected mean value for North Sumatra

(Freundlich)<sup>23</sup> is 2" 20

The value with the probable errors (Lanczos<sup>24</sup>) is 2' 20 ± 0" 10

The results of the above expeditions, including some others, and the effect of the corrections will be more fully discussed in Chapter III

3 (i) In Relativity the fundamental equation is

$$ds^2 = dx^2 + dy^2 + dz^2 + c^2 (\sqrt{1 - k\theta^2} dt)^2 \quad (14.2)$$

Hence for a body moving with the speed of light  $ds=0$  Accordingly

$$h = r \frac{d\phi}{ds} = \infty \quad \dots \quad (14.3)$$

Thus there is no option but to assume  $h$  to be infinite. But if a ray of light from a star passes round the sun,  $r \frac{d\theta}{dt}$  can never exceed the tangential velocity  $c$ ; and so  $h = r^2 \frac{d\theta}{dt}$  can never exceed  $r \cdot c$ . When the arc of the hyperbolic path near the sun is almost circular  $h = r \cdot c$ . Both  $r$  and  $c$  being finite,  $h$  cannot possibly be infinite. Hence in equation (8.1) it is wrong

to neglect  $\frac{\mu}{h^2}$  and treat it as zero. The term  $\frac{2\mu}{Dh} \frac{du}{d\theta}$  which equals  $-\frac{2\mu}{Dh^2} \frac{dr}{dt}$  is certainly very small, particularly when in a nearly circular arc  $\frac{dr}{dt}$  is nearly zero and also changes sign. This may be neglected, but the remaining two terms are of the same order.

As  $h$  is not greater than  $r$  or

$$\frac{\mu}{h^2} \text{ is not less than } \frac{\mu}{c^2} u^2$$

$$\text{Hence } \frac{d^2u}{d\theta^2} + u = \frac{\mu}{c^2} u^2 + \frac{3\mu}{D^2} u^2 \text{ at least} \quad (14.4)$$

$$= \frac{4\mu}{c^2} u^2 \text{ where } D=c \quad \dots \quad (14.5)$$

Comparing this equation with (8'6), it is at once seen that the real deflection is nearly  $\frac{4}{3}$  times the value of Einstein's, which is twice that of Newton's.

Accordingly the angle of deflection is

$$\begin{aligned} &= \frac{4}{3} \times 0' 87 = 2' 66 \text{ times that of Newton's} \\ &= 2'' 32 \quad \dots \quad \dots \quad \dots \quad (14'6) \end{aligned}$$

This accords with the observed values quoted in the preceding paragraph. It is submitted that as the large excess over Einstein's value destroys the fundamental assumption in Relativity that  $ds=0$ , the very observation of the deflection of light which was at one time believed to have verified Relativity must now be taken to disprove it.

4. The effect of refraction through the corona of the sun, treated as a medium of concentric spheres, with density decreasing as a function of the distance from the centre, is very small if the index of refraction is small.

(i) As  $\mu \sin \phi = (\mu + d\mu) \sin (\phi - d\epsilon) = \mu \sin \phi - \mu \cos \phi d\epsilon + d\mu \sin \phi$

$$d\mu \sin \phi = \mu \cos \phi d\epsilon \quad \text{or} \quad \frac{d\mu}{\mu} = \frac{d\epsilon}{\tan \phi}$$

Hence if at the surface of the sun the values be  $\mu = \mu_0$ ,  $r = a$  and  $\phi = \alpha$ , then

$$\begin{aligned} \frac{d\epsilon}{d\mu} &= \frac{1}{\mu} \sqrt{\frac{\mu_0 a \sin \alpha}{\mu^2 r^2 - \mu_0^2 a^2 \sin^2 \alpha}} \\ \epsilon &= \mu_0 a \sin \alpha \int_0^{\mu_0} \frac{d\mu}{\mu \sqrt{\mu^2 r^2 - \mu_0^2 a^2 \sin^2 \alpha}} \dots \dots \quad (14.7) \end{aligned}$$



(ii) Also as  $r\mu \sin\phi = r\mu' \sin\phi'$ ,  $\mu p = \mu' p' = h$

Hence 
$$\mu^2 = \frac{h^2}{p^2} = h^2 \left[ u^2 + \left( \frac{du}{d\theta} \right)^2 \right]$$

When the ray is approaching the sun,  $\frac{du}{d\theta}$  is positive

Therefore  $\theta = \int \frac{u}{\sqrt{\mu^2 - h^2 u^2}} du$  gives the equation for the path of the ray

(14.8)

### SECTION III

#### THE SHIFT OF THE FRAUNHOFER LINES

1 In the New Theory, light is regarded as a mere particle of matter called "radion" If a radion comes straight from the Sun to the Earth, then in (5.7)  $\frac{d\theta}{dt} = 0$  So there will be no aberration

Further as the velocities of gravitons and radions are about the same, there will be no effect of the Doppler principle A radion will travel from the Sun to the Earth, surrounded by gravitons travelling with an equal velocity The only effect will be that gravitons will be expanding in spherical surfaces, and therefore their intensity round about the radion will gradually diminish as the inverse square of the distance

The equation will simply be  $\frac{d^2 r}{dt^2} = -\frac{GM}{r^2}$  During the path, the radion will be attracted both by the Sun and the Earth If  $M$  and  $m$  be the masses,  $a$  and  $b$  the radii of the Sun and the Earth and  $d$  the distance between them, then measuring  $r$  from the centre of the Sun,

$$\begin{aligned} V^2 &= V_0^2 + 2G \int \left[ -\frac{M}{r^2} + \frac{m}{(d-r)^2} \right] dr \\ &= V_0^2 + 2G \left[ \frac{M}{r} + \frac{m}{(d-r)} \right] \end{aligned} \quad (15.1)$$

(i) If  $c$  be the velocity of the radion at  $\infty$ , then  $V_0 = c$

$$\text{At the Sun } V_a^2 = c^2 + 2G \left( \frac{M}{a} + \frac{m}{d-a} \right)$$

$$\text{At the Earth } V_b^2 = c^2 + 2G \left( \frac{M}{d-b} + \frac{m}{b} \right)$$

Now a particle starting from the Sun with velocity  $V_s$  will have its velocity reduced at the Earth to  $V_e$ . It would, therefore, seem at the Earth as if the solar atoms had lower frequencies, *i.e.*, greater periods in the ratio

$$\frac{T_s}{T_e} = \left( \frac{V_s^2}{V_e^2} \right)^{\frac{1}{2}} = \frac{1 + \frac{G}{c^2} \left( \frac{M}{a} + \frac{m}{d-a} \right)}{1 + \frac{G}{c^2} \left( \frac{M}{d-b} + \frac{m}{b} \right)} \text{ nearly} \quad (15.2)$$

(ii) Or if the velocity at the Sun be taken to be  $c$  then  $V_s = c$  and

$$\begin{aligned} V_e^2 &= c^2 - 2G \left( \frac{M}{a} + \frac{m}{d-a} \right) \\ \frac{T_s}{T_e} = \frac{V_s}{V_e} &= \left[ 1 - 2 \frac{G}{c^2} \left( \frac{M}{a} + \frac{m}{d-a} \right) + 2 \frac{G}{c^2} \left( \frac{M}{d-b} + \frac{m}{b} \right) \right]^{\frac{1}{2}} \\ &= \frac{1 + \frac{G}{c^2} \left( \frac{M}{a} + \frac{M}{d-a} \right)}{1 + \frac{G}{c^2} \left( \frac{M}{d-b} + \frac{m}{b} \right)} \text{ nearly} \quad (15.2) \end{aligned}$$

(iii) The equation (15.2) reduces approximately to

$$\frac{T_s}{T_e} = \frac{1 + \frac{G}{c^2} \cdot \frac{M}{a}}{1 + \frac{G}{c^2} \cdot \frac{m}{b}} \text{ as } d \text{ is large} \quad (15.3)$$

This is the formula deduced by Einstein in Relativity. He puts it in astronomical units as —

$$\frac{1 + \frac{M}{R}}{1 + \frac{m}{r}}$$

2 (i) The calculated values are as follows —

$$\begin{aligned} \frac{G}{c^2} \cdot \frac{m}{b} \text{ for the Earth} &= \frac{5.974 \times 10^{27} \times 6.658 \times 10^{-8}}{(2.9986)^2 \times 10^{10} \times 6371 \times 10^3} \\ &= .000,000,000,69 \end{aligned}$$

$$\begin{aligned} \frac{G}{c^2} \cdot \frac{m}{a} \text{ for the Sun} &= \frac{1.983 \times 10^{30} \times 6.658 \times 10^{-8}}{(2.9986)^2 \times 10^{10} \times 6955 \times 10^3} \\ &= .00000211 \end{aligned}$$

$$\begin{aligned} \frac{G}{c^2} \frac{M}{d} \text{ for the Sun and the Earth} \\ = \frac{1.983 \times 10^{33} \times 6.658 \times 10^{-8}}{(2.9986)^2 \times 10^{30} \times 14945 \times 10^9} \\ = 000,000,0098 \end{aligned}$$

Accordingly, the corrections provided by New Relativity are not appreciably large, and the value of the ratio is the same as Einstein's and

$$= 1.000002111 \quad (15.4)$$

The displacement of the blue light ( $\lambda = 4000 \text{ \AA}$  U) is

$$4000 \times 0.00002111 = 0.08444 \text{ \AA U}$$

(ii) The observed value as given by St John<sup>10</sup> (1917) = 0.036 \text{ \AA U}

(iii) St. John also once found the displacement to be 0.00 for cyanogen lines. The possibility for such a small value, as also the values obtained by Evershed (1914, 1918), Schwarzschild (1914) and Grebe and Bachem (1919), will be discussed in Chapter III.

3 It may here be pointed out that as the theoretical value tallies approximately with the observed value, it disproves the assumption in Relativity that the velocity of light in a gravitational field remains constant. A change in the medium of course alters the velocity, but it now appears that a change in the gravitational potential also is effective.

4 In Relativity the formula for the ratio of vibrations is obtained from the equation  $ds^2 = -\frac{1}{\gamma} dr^2 - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 + \gamma dt^2$  (where a particular solution gives  $\gamma = 1 - \frac{2m}{r}$ ) by treating the atoms at rest and therefore putting  $dr = d\theta = d\phi = 0$ , which give  $ds^2 = \gamma dt^2$ , or  $\frac{dt}{ds} = \frac{1}{\sqrt{\gamma}} = \left(1 + \frac{m}{r}\right)$  nearly.

It is submitted that when absolute motion is denied, the assumption of an absolute rest is illogical.

#### SECTION IV

##### THE COMPANION OF SIRIUS

1 For the companion of Sirius, the theoretical value first tallied with the observed value.

For the companion ( $\alpha$  canis maj ' B ), the ratio

$$\begin{aligned} \frac{M_2}{a_2} &= \frac{96 \text{ of sun's mass}}{0.34 \text{ of sun's radius}} \\ &= 28 \text{ times the ratio for the sun} \end{aligned}$$

The displacement of the Fraunhofer lines should therefore be about 28 times

The observed displacement is about 30 times

2. But Vyssotskiy<sup>10</sup> has recently found that the density of the companion is much less, and therefore its radius much larger

If this be right then the observed value would be about half as much as the theoretical value, giving the same discrepancy as in the case of the sun

3 It is easy to see that the gravitational effect of Sirius A on the light from Sirius B would be negligible Let their masses be  $M_1$  and  $M_2$ , radii be  $a_1$  and  $a_2$ , the distance between them be  $p$  and their distance from the Earth be  $d$

Let  $r$  be the distance of a radion from  $S_B$  and  $R$  its distance from  $S_A$  and let  $\theta$  be the angle between  $r$  and  $R$

$$\begin{aligned} \text{Then } V^2 &= V_0^2 + 2 \int -\frac{GM_2}{r^2} dr + 2 \int -\frac{GM_1}{R^2} \cos \theta dr \\ &= V_0^2 + 2 \frac{GM_2}{r} + \frac{GM_1}{p} \left( \theta + \frac{\sin^2 \theta}{2} \right) \end{aligned} \quad (16.1)$$

If  $V=c$  at  $S_B$  where  $r=a_2$  and  $\theta=\frac{\pi}{2}$ , then  $V_0^2 = c^2 - 2 \frac{GM_2}{a_2} - \frac{GM_1 \pi}{2p}$

Also when  $r=d-a=d$  nearly and  $\theta=0$  nearly, we have

$$V_c^2 = c^2 - \frac{2GM_2}{a_2} - \frac{GM_1 \pi}{2p} + \frac{2GM_2}{d}$$

$$\text{Hence } \frac{V_c}{V_0} = 1 + \frac{G}{c^2} \left[ \frac{M_2}{a_2} + \frac{M_1 \pi}{4p} \right] \quad (16.2)$$

It is thus apparent that  $p$  being very large in comparison with  $a_2$ , the effect of the second term is almost nil

## SECTION V

### THE PLANETS AND THE STARS

On the analogy of (15.2) the formulæ for the superior and inferior planets can be put down at once

1 (i) When Jupiter is behind the Sun, and  $M'$  is its mass and  $d_1$  its distance from the Sun,

$$\frac{T_s}{T_e} = \frac{1 + \frac{M}{a} + \frac{M'}{a+d_1} + \frac{m}{d-a}}{1 + \frac{M}{d-b} + \frac{M'}{d+d_1-b} + \frac{m}{b}} \dots \dots \dots (17.1)$$

(ii) When Jupiter is behind the Earth

$$\frac{T_s}{T_e} = \frac{1 + \frac{M}{a} + \frac{M'}{d_1 - a} + \frac{m}{d - a}}{1 + \frac{M}{d - b} + \frac{M'}{d_1 - d + b} + \frac{m}{b}} \quad (172)$$

2 (i) When Venus ( $m_2, d_2$ ) is behind the Sun

$$\frac{T_s}{T_e} = \frac{1 + \frac{M}{a} + \frac{m_2}{a + d_2} + \frac{m}{d - a}}{1 + \frac{M}{d - b} + \frac{m_2}{d + d_2 - b} + \frac{m}{b}} \quad (173)$$

(ii) When Venus is between the Sun and the Earth, the effect of Venus is practically nullified as light from the Sun to the Earth approaches to and recedes from Venus

3 Unfortunately, the ratios for the planets are too small as compared to that for the Sun, and the more accurate formulæ cannot give any better results at present

4 Similarly the ratio for an ordinary star or nebula is too small. For example, the value of  $\frac{GM}{c^2 a}$  for M 31 (in Andromeda) comes to 0000000238 which is negligible

5 Another White Dwarf (40 Eridani B) has the ratio

$$\frac{M'}{a'} = \frac{44M}{019a} = 231 \frac{M}{a}$$

Its displacement is therefore large enough and the measurement when made will furnish another test

## SECTION VI

### EXPERIMENTS RECONCILED

1. **Airy** and **Hook** found that the direction in which a star is seen remains unaltered, whether the telescope be filled with air or water. In the wave theory of light this implies that the ether waves inside matter must be *partially* carried along by the moving matter with a velocity diminished in the ratio  $\left(1 - \frac{1}{\mu^2}\right)$ , where  $\mu$  is the index of refraction. On the other hand, **Michelson** and **Morley's** experiment on the interference fringes with monochromatic light showed that it makes no difference

whether light travels backwards and forwards along the direction of the Earth or in a direction perpendicular to it, which implies that ether just outside a moving matter is *wholly* carried along with the velocity of the moving matter. The two results are irreconcilable.

2. But if a light particle from a star is arriving at a telescope with velocity  $c$  and finds the telescope moving horizontally with a velocity  $u$ , then the resultant effect is the same as if the telescope were reduced to rest, and an equal and opposite velocity— $u$  be added to the velocity of light. By tilting the telescope appropriately, the resultant path of light can be made to lie along the axis of the telescope. When the telescope is relatively at rest the resultant path cannot change its direction when the telescope is filled with water instead of air, only the relative velocity of light along the axis is decreased in water. The decrease of the velocity in water is the same both vertically and horizontally; hence the resultant path in spite of the reduced velocity remains unchanged.

3 (1) In Michelson and Morley's experiment monochromatic light produced on the earth has to be used. Like ordinary particles of matter it already possesses the velocity of the earth in addition to its own velocity  $c$ . This has been overlooked by the experimenters.

According to Newton's law  $c+v \neq c-v \neq c$

Einstein gives to  $c$  the properties of infinity although  $c$  is finite. He arbitrarily assumes that  $c+v=c$  and  $c-v=c$ . It is by this strange hypothesis that he tries to explain the result obtained by Michelson and Morley, but his is not an explanation but a mere assumption.

The real explanation is that Michelson and Morley misinterpreted their experiment. What they thought to be  $c$  was really  $(c-v)$  in one direction and  $(c+v)$  in the opposite direction, and so

$$\frac{1}{(c-v)+v} + \frac{1}{(c+v)-v} \equiv \frac{1}{c} + \frac{1}{c}$$

"The corpuscular theory had implied a different mode of travel if it travelled like particles shot out from a gun, then its speed of travel would be always the same *relative to the gun from which it was fired*. "Does light travel like waves or like particles?" When the question is framed in this way, the Michelson-Morley experiments unambiguously support the latter alternative" (James Jeans)<sup>16</sup>

4. The stumbling block in the way of the corpuscular theory of light has been the phenomena of interference and diffraction. In my Unified Theory of Physical Phenomena it has been shown that all the

phenomena including interference and diffraction can be easily explained on a Rotational Theory of light. If a beam of monochromatic light consists of a swarm of material particles, either rotating round their path of longitudinal motion or even spinning round their own axes with one uniform period, a permanent difference in the phase of the resultant effect will be obtained, if the beam be split up into two parts, one of which travels along a longer distance than the other. When the two are made to rejoin, successive maximum and minimum effects will be produced, which would be periodic, and will necessarily cause the phenomena of interference. Rotating radions will thus possess both the particle and the wave aspects simultaneously, reconciling the phenomena of diffraction and scintillation.

## SECTION VII

## THE CHARACTERISTICS OF THE ORBIT

The equations are —

$$-\frac{d^2 r}{dt^2} - r \left( \frac{d\theta}{dt} \right)^2 = -\frac{\mu}{r^2} - \frac{3\mu}{D^2} \frac{h^2(1+k\theta)^2}{r^4} + \frac{3\mu}{D} \frac{1}{r^3} \frac{dr}{dt} \quad (5.7)$$

$$\frac{d^2 u}{d\theta^2} - 2 \frac{k}{1+k\theta} \frac{du}{d\theta} + u = \frac{\mu}{h^2(1+k\theta)^2} + \frac{3\mu}{D^2} u^2 \dots \quad (5.9)$$

$$\text{and } u = \frac{\mu}{h^2(1+k\theta)^2} \left[ 1 + E(1+k\theta)^2 e^{1+\frac{k\theta}{h}} \cos(\theta - m - \epsilon) \right] \text{ nearly}$$

$$\text{where } \epsilon = \frac{3\mu^2}{D^2 h^2} \frac{\theta}{(1+k\theta)^2} \dots \quad (11.13)$$

1. If  $\frac{1}{r} = \alpha + \beta \cos \theta$  for an ellipse, then

$$\frac{1}{SA} = \alpha + \beta \text{ and } \frac{1}{SA'} = \alpha - \beta$$

From these  $a = \frac{\alpha}{\alpha^2 - \beta^2}$ ,  $b = \frac{1}{\sqrt{\alpha^2 - \beta^2}}$  and  $e = \frac{\beta}{\alpha}$

Hence if (11.13) be treated as resembling an ellipse, then roughly speaking

$$(i) \text{ its semi-major axis} = \frac{1}{\mu} h^2 (1 + k\theta)^2 \text{ as observed,} \quad (18.1)$$

$$(ii) \text{ its semi-minor axis} = \frac{h^4}{\mu^2} \frac{1}{1 - E^2 - 4k\theta} \text{ as observed,} \quad (18.2)$$

$$\text{and (iii) its eccentricity} = E \frac{k\theta}{1 + k\theta} (1 + k\theta)^2 \text{ as observed,} \quad (18.3)$$

2. These suggest that the orbit has the following characteristics in contrast with the Newtonian orbit

- (a) It rotates round the Sun at a measurable speed
- (b) Its major axis has a tendency to increase very slowly
- (c) Its minor axis also has a tendency to increase, but slightly less slowly
- (d) Its eccentricity has a tendency to increase slowly
- (e) The orbit, therefore, tends to enlarge in size, but becomes slightly elongated.
- (f) The orbit instead of becoming more and more circular tends to approach a parabola
- (g) Planets are tending to resemble comets, until the parabolic path is reached when they would leave the solar system

3. From (5.7) it is apparent that the last term changes its sign, while the others do not, as the planet approaches to or recedes from the Sun. At corresponding points in the orbit, the other terms have equal magnitudes and are directed towards the Sun. But the last term which contains  $\frac{dr}{dt}$  has an additive effect for half the orbit and a subtractive effect for the other half. The net result is a gain of attraction towards the Sun. For ordinary planets (except perhaps Mercury) the orbits are nearly circular and  $\frac{dr}{dt}$  is very small. It is small even for Mercury, but the term is appreciable in the case of comets and an increased velocity can be noticeable.

4. The value for the changes in the elements have been obtained in (12.5), (12.8) and (12.12). They also show that:—

- (i)  $\Delta a$  has a tendency to increase,
  - (ii)  $\Delta e$  has a tendency to increase,
- and that (iii)  $\Delta \omega$  is increasing at a measurable rate



These give the approximate results. But we must remember that what we observe are  $T' = T + \Delta T$ ,  $a' = a + \Delta a$ , and  $e' = e + \Delta e$ . These therefore hardly show any variations. On the other hand  $\Delta\omega$  is actually observed as increasing slowly.

#### CHAPTERS III AND IV

1. Chapter III will deal more fully with the values for (a) the deflection of light, (b) the displacement of the Fraunhofer lines, for (i) the sun, and (ii) the companion of Sirius, and (c) the advance of the perihelion of the inner planets.

2. The apparent velocities of approach of some of the nearest nebulae can be considerably reduced by taking into account the galactic motion, but they do not *wholly* disappear, and even if they disappear the corrections cannot produce velocities of recession proportional to their distances. Relativity completely fails in this respect. See Prof. J. H. Reynold's<sup>21</sup> article in *Nature*, Vol. CXXX, July to December (1932), pp. 458—462.

It will be shown in Chapter IV how under the equations, Nebulae, without any force of cosmic repulsion, can have velocities proportional to distances both of recession and approach, and how the equations lead to a stable and not an exploding universe.

3. Fizeau's experiment will become easily intelligible and so would De Sitter's conclusion from the test of Binary stars that the velocity of light is independent of the velocity of the source in the direction of its motion (though not transversely).

4. An attempt will be made in Part II to show that the Universe is cyclic.

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# A THEOREM CONCERNING THE ZEROS OF THE LAPLACE-ABEL INTEGRAL

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In this note I propose to prove a theorem for the Laplace-Abel integral analogous to Theorem 6 of the Cambridge Tract No 18 for the Dirichlet's series. The theorem in view may be stated as follows —

*Theorem —*

*If*

(1)  $\varphi(x)$  is an analytic function of  $x (=x+iy)$  in the interior of the strip  $|y| \leq k$ ,  $x \geq -\delta$ , where  $k$  and  $\delta$  are some positive numbers, and satisfies the inequality

$$\varphi(x) = O(e^{Mx})$$

uniformly throughout this strip as  $|x| \rightarrow \infty$ ,

(2)  $f(s) = \int_0^\infty \varphi(x) e^{-sx} dx$ , which is certainly an analytic function

of  $s$  in the half plane  $\sigma \geq M + \delta_1 > M$ ,  $\delta_1 > 0$ , possesses an infinity of zeros in this half plane,

then  $f(s)$  is identically zero

Suppose  $s_1, s_2, s_3, \dots, s_n$  are the zeros of  $f(s)$ . Then, since the zeros of an analytic function are isolated,  $s_n \rightarrow \infty$  as  $n \rightarrow \infty$  in the half-plane  $\sigma \geq M + \delta_1 > M$ .

Take a point  $P(x)$  on the real axis in the  $x$ -plane. If  $x$  be sufficiently large, then we can describe a circle  $C$  of radius  $e^{-\epsilon x}$  round  $P$  such that  $C$  lies wholly within the strip defined in (1),  $\epsilon$  being an arbitrarily small positive number. By Cauchy's theorem, we shall have then

$$\varphi^\mu(x) = \frac{\mu!}{2\pi i} \int_C \frac{\varphi(z) dz}{(z-x)^{\mu+1}}$$

so that

$$|\varphi^\mu(x)| < K \mu! e^{\mu \epsilon x} e^{M(x + e^{-\epsilon x})}$$

i.e.,

(3)  $\varphi^\mu(x) = O(e^{(M + \epsilon \mu)x})$ , for  $\mu = 0, 1, 2, 3, \dots$

Now consider

$$sf(s) = s \int_0^{\infty} \varphi(x) e^{-sx} dx,$$

the integral being absolutely and uniformly convergent throughout the half-plane  $\sigma \geq M + \delta_1 > M$

Integrating by parts, we have if  $\sigma \geq M + \delta_1 > M$ .

$$\begin{aligned} (4) \quad sf(s) &= \left\{ -\varphi(x) e^{-sx} \right\}_0^{\infty} + \int_0^{\infty} \varphi'(x) e^{-sx} dx \\ &= \varphi(0) + \int_0^{\infty} \varphi'(x) e^{-sx} dx \\ &= \varphi(0) + \left\{ -\frac{\varphi'(x) e^{-sx}}{s} \right\}_0^{\infty} + \frac{1}{s} \int_0^{\infty} \varphi''(x) e^{-sx} dx, \\ &= \varphi(0) + \frac{\varphi'(0)}{s} + \frac{1}{s} \int_0^{\infty} \varphi''(x) e^{-sx} dx, \end{aligned}$$

[by virtue of (3)]

Now the integral  $\int_0^{\infty} \varphi''(x) e^{-sx} dx$ , being absolutely and uniformly convergent throughout the half-plane  $\sigma \geq M + \delta_1 > M$ , is bounded in this half-plane. So that, the right side of (4) tends to  $\varphi(0)$  as  $s \rightarrow \infty$  in this half-plane. But by hypothesis  $sf(s)$  also vanishes for a sequence of values of  $s$  in the same half-plane whose limit is infinity. Hence  $\varphi(0) = 0$ , that is

$$(5) \quad sf(s) \equiv f_1(s) = \int_0^{\infty} \varphi'(x) e^{-sx} dx$$

Now, applying the same argument to  $f_1(s)$  as we did to  $f(s)$  above, we can prove that  $\varphi'(0) = 0$ . Similarly, we can prove that  $\varphi''(0) = \varphi'''(0) = \dots = 0$ . It follows, therefore, that the function  $\varphi(x)$ , analytic in the neighbourhood of the origin, vanishes along with all its successive derivatives at the origin, and so  $\varphi(x)$  is identically zero. Consequently,  $f(s)$  vanishes identically. This proves the theorem.

I wish to thank Dr P. L. Srivastava, under whose guidance the paper was written.

# ON THE SUMMABILITY OF FOURIER SERIES BY ARITHMETIC MEANS

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1. Let  $f(x)$  be a function periodic and integrable in the sense of Lebesgue in  $(-\pi, \pi)$  and let its Fourier series be

$$\frac{1}{2}a_0 + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx) \quad (1.1)$$

In what follows we shall put

$$\phi(t) = \frac{f(x+2t) + f(x-2t) - 2S}{2},$$

and

$$\Phi(t) = \int_0^t \phi(u) du$$

The Cesàro summability, index unity, of a Fourier series at a point of continuity or simple discontinuity has been entirely disposed of by the classical theorem<sup>1</sup> of Fejér. Thereafter the question of finding criteria to be satisfied at points of discontinuity of the second kind became an important one. This question was taken up by Lebesgue who proved a more general theorem<sup>2</sup> which is applicable at all points at which

$$\lim_{t \rightarrow 0} \{f(x+2t) + f(x-2t)\}$$

exists and it may be valid even at points of discontinuity of the second

<sup>1</sup> Fejér, 4.

<sup>2</sup> Lebesgue, 9, 274.

kind. Later on Young generalized<sup>1</sup> Lebesgue's criterion, but curiously enough, until quite recently, this criterion of Young seems to have remained unnoticed.

All these criteria are essentially applicable *only* at points where the limit

$$\lim_{t \rightarrow 0} \frac{\Phi(t)}{t} \quad (1'2)$$

exists. If we impose upon  $f(x)$  the restriction of being bounded, or  $f(x) > -A$ ,  $A$  being a constant, then, as shown by Hardy and Littlewood,<sup>2</sup> the existence of this limit is the necessary and sufficient condition for the Cesàro summability of every positive order.<sup>3</sup> Cases, however, are known in which the Fourier series is summable  $(\sigma, 1)$  even when the limit (1'2) does not exist.<sup>4</sup> But a general discussion of the summability  $(\sigma, 1)$  of unrestricted functions  $f(x)$  for which the limit (1'2) does not exist, seems to be lacking.

The object of this paper is to indicate a general simple method by which all these known criteria and several new ones can be obtained in a natural, connected manner. The underlying principle of the method is to reduce the discussion of the summability  $(\sigma, 1)$  of the Fourier series corresponding to  $\phi(t)$  to that of the ordinary convergence of the Fourier series corresponding to  $\Phi(t)/t$ . The method will be applicable even to cases in which the limit (1'2) does not exist.

2 We have for the partial sum of the Fourier series

$$s_n(x) = \frac{1}{2}a_0 + \sum_{m=1}^{m=n} (a_m \cos mx + b_m \sin mx)$$

<sup>1</sup> Young, 15, 207, Corollary 4.

<sup>2</sup> Hardy and Littlewood, 7.

<sup>3</sup> There seems to have been some misconception about the connection between the existence of the limit (1'2) and the summability  $(\sigma, 1)$  of the corresponding Fourier series. For instance we find in Hobson's *Theory of Functions of a Real Variable*, Vol 2 (1926),

pp 570-571, the statement that the condition  $\int_0^t \phi(t)dt = o(t)$  "although *necessary*, is not

sufficient, for the convergence  $(\sigma, 1)$  of the Fourier series" (italics ours). In fact the truth is that this condition is *neither necessary nor sufficient* for the summability  $(\sigma, 1)$  of the Fourier series.

<sup>4</sup> For instance, see G. Prasad, 13.

$$s_n(x) = \frac{1}{\pi} \int_0^{\pi/2} \left\{ f(x+2t) + f(x-2t) \right\} \frac{\sin(2n+1)t}{\sin t} dt \quad (2'1)$$

If  $s_n(x)$  represents the Cesàro  $n^{\text{th}}$  partial sum of the Fourier series, we have

$$\begin{aligned} s_n(x) &= s_0 + s_1 + s_2 + \dots + s_{n-1} \\ &= \frac{2}{n\pi} \int_0^{\pi/2} \left\{ f(x+2t) + f(x-2t) \right\} \left( \frac{\sin nt}{\sin t} \right)^2 dt \end{aligned}$$

Since

$$\int_0^{\pi/2} \left( \frac{\sin nt}{\sin t} \right)^2 dt = n \frac{\pi}{2},$$

$s_n(x)$  will tend to  $S$  as  $n \rightarrow \infty$ , and the Fourier series will be summable  $(c, 1)$ , if the integral

$$\begin{aligned} &\frac{2}{n\pi} \int_0^{\pi/2} \left\{ \frac{f(x+2t) + f(x-2t)}{2} - S \right\} \left( \frac{\sin nt}{\sin t} \right)^2 dt \\ &= \frac{2}{n\pi} \int_0^{\pi/2} \phi(t) \left( \frac{\sin nt}{\sin t} \right)^2 dt \end{aligned} \quad (2'2)$$

tends to zero, as  $n \rightarrow \infty$ .

3. Theorem I *The Fourier series corresponding to  $\phi(t)$  will be summable  $(c, 1)$  at a point  $x$ , if the Fourier series corresponding to  $\phi(t)/t$  is convergent in the ordinary sense at that point*<sup>1</sup>

If  $\delta$  be a number which may be chosen arbitrarily small, but greater than zero and independent of  $n$ , then we have

$$\frac{2}{n\pi} \int_{\delta}^{\pi/2} \phi(t) \left( \frac{\sin nt}{\sin t} \right)^2 dt = o(1)$$

<sup>1</sup> Long after I had proved this theorem I happened to see a theorem of W H Young which is substantially the same as this (see Young, 14, p. 266, theorem 8) But Young's proof and those of mine are of *entirely* different character from each other Young first establishes a number of relations involving Fourier coefficients and therefrom he deduces his theorem As will be observed, Young's proof is lengthy, complicated and very indirect, whereas the proofs given here are very concise, straightforward and (especially the second) very direct.

Hence the Fourier series will be summable  $(c, 1)$  at  $x$ , if the integral

$$I_n = \frac{1}{n\pi} \int_0^\delta \phi(t) \left( \frac{\sin nt}{t} \right)^2 dt$$

is  $o(1)$  Integrating the above by parts, we get

$$I_n = \left[ \frac{1}{n\pi} \Phi(t) \left( \frac{\sin nt}{t} \right)^2 \right]_0^\delta - \frac{1}{n\pi} \int_0^\delta \Phi(t) \frac{d}{dt} \left( \frac{\sin nt}{t} \right)^2 dt$$

The term in the square brackets being  $o(1)$ , the Fourier series will be summable  $(c, 1)$ , if each of the integrals

$$\frac{1}{\pi} \int_0^\delta \frac{\Phi(t)}{t} \frac{\sin 2nt}{t} dt \quad (3.1)$$

$$\text{and} \quad \frac{1}{n\pi} \int_0^\delta \frac{\Phi(t)}{t} \left( \frac{\sin nt}{t} \right)^2 dt \quad (3.2)$$

is  $o(1)$

Supposing  $\Phi(t)/t$  to be integrable, the Fourier series corresponding to  $\Phi(t)/t$  [in the same sense in which in the usual terminology, a Fourier series corresponds to  $\phi(t)$ ] will be convergent, if (3.1) is  $o(1)$ . In that case since (3.2) will behave as the Cesàro  $n$ th partial sum, (3.2) must also be  $o(1)$ . Hence we conclude that whenever (3.1) is  $o(1)$ , (3.2) is also  $o(1)$ . This proves the theorem.

4 As we have just seen, the proof of the theorem consists in showing that whenever the integral (3.1) is  $o(1)$ , the integral (3.2) is also  $o(1)$ , and this we have proved by interpreting these integrals in terms of Fourier series. We can, however, prove this in a very direct manner which is free from the notions of Fourier series. We make the statement in a form connecting Dirichlet and Fejér integrals and as such it may prove of wider applicability.

**Theorem II** *If the integral*

$$\int_0^\delta \chi(t) \frac{\sin 2nt}{t} dt$$

is  $o(1)$  as  $n \rightarrow \infty$ , then also the integral

$$\frac{1}{n} \int_0^\delta \chi(t) \left( \frac{\sin nt}{t} \right)^2 dt$$

is  $o(1)$



The proof of it depends upon the following well-known simple lemma —

Lemma. If  $c_n \rightarrow 0$ , as  $n \rightarrow \infty$ , then

$$\sigma_n = \frac{c_1 + c_2 + c_3 + \dots + c_n}{n}$$

also tends to zero, as  $n \rightarrow \infty$

Now taking 
$$c_n = \int_0^\delta \chi(t) \frac{\sin 2nt}{t} dt,$$

$$\begin{aligned} \text{we have } \sigma_n &= \frac{1}{n} \int_0^\delta \frac{\chi(t)}{t} \frac{\sin nt \sin (n+1)t}{\sin t} dt \\ &= \frac{1}{n} \int_0^\delta \frac{\chi(t)}{t} \frac{\sin^2 nt}{\sin t} \cos t dt + \frac{1}{n} \int_0^\delta \frac{\chi(t)}{t} \sin nt \cos nt dt \\ &= \frac{1}{n} \int_0^\delta \chi(t) \left( \frac{\sin nt}{t} \right)^2 dt + o(1) + \frac{1}{2n} \int_0^\delta \chi(t) \frac{\sin 2nt}{t} dt \\ &= \frac{1}{n} \int_0^\delta \chi(t) \left( \frac{\sin nt}{t} \right)^2 dt + o(1) + o(1) \end{aligned}$$

Thus 
$$\frac{1}{n} \int_0^\delta \chi(t) \left( \frac{\sin nt}{t} \right)^2 dt = o(1)$$

5 In order to deduce criteria for the summability  $(c, 1)$  of Fourier series, let us divide the discussion according as (i) the  $\lim_{t \rightarrow 0} \Phi(t)/t$  is zero, or (ii) this limit does not exist, but  $\Phi(t)/t$  possesses at  $t=0$ , a finite or infinite discontinuity of the second kind

Taking the case (i), if we apply to

$$\frac{1}{\pi} \int_0^\delta \frac{\Phi(t)}{t} \frac{\sin 2nt}{t} dt$$

the various known standard tests of the ordinary convergence of a Fourier series, we shall get as many criteria for the summability  $(c, 1)$ . Out of these the application of Jordan's test<sup>1</sup> gives a criterion which is merely de la Vallée-Poussin's test<sup>2</sup> of the ordinary convergence and as such it must be rejected. We thus get the following criteria.—

<sup>1</sup> Jordan, §

<sup>2</sup> de la Vallée-Poussin, 1, also 2, 149

By the application of Lipschitz's test<sup>1</sup> —

(A) *The Fourier series will be summable (c, 1), if*

$$\left| \int_0^t \phi(t) dt \right| = At^{k+1}$$

*for all values of t not greater than some fixed positive number a,  
A and k being some fixed positive number*

By the application of de la Vallée-Poussin's test —

(B) *The Fourier series will be summable (c, 1), if an interval (0, a) can be found in which*

$$\frac{1}{t} \int_0^t dt \frac{1}{t} \int_0^t \phi(t) dt$$

*is of bounded variation*

By the application of W H Young's test<sup>2</sup> —

(C) *The Fourier series will be summable (c, 1), if*

$$\int_0^t \left| \phi(t) \right| dt = O(t)$$

This is the generalized form of Lebesgue's criterion due to Young  
A direct proof of it has been given by Pollard<sup>3</sup>

By the application of Lebesgue's test<sup>4</sup> —

(D) *The Fourier series will be summable (c, 1), if*

$$\lim_{\epsilon \rightarrow 0} \int_{\epsilon}^{\xi} \left| \frac{\Phi(t+\epsilon)}{t+\epsilon} - \frac{\Phi(t)}{t} \right| dt = 0,$$

$\xi$  being a constant greater than  $\epsilon$

From the consideration of the logical relations between the various criteria for the convergence of Fourier series,<sup>5</sup> it follows that (D) includes all the first three, (B) includes (A), while (B) and (C) are independent of each other

6 Taking the case (ii) in which  $\Phi(t)/t$  has got a discontinuity of the second kind at  $t=0$ , the problem is reduced to the discussion of the oscillating Dirichlet's integral

<sup>1</sup> Lipschitz, 10

<sup>2</sup> Young, 15 206.

<sup>3</sup> Pollard, 11

<sup>4</sup> Lebesgue, 9

<sup>5</sup> Hardy, 5

$$\int_0^b \frac{\Phi(t)}{t} \frac{\sin 2nt}{t} dt$$

By the application of Du Bois-Reymond's test,<sup>1</sup> we get the following criterion —

$$(E) \quad \text{If} \quad \frac{\Phi(t)}{t} = \rho(t) \cos \sigma(t),$$

where each of  $\rho(t)$  and  $\sigma(t)$  is monotone in  $(0, b)$  and at least  $\sigma(t)$  is unlimited, then the Fourier series will be summable  $(c, 1)$ , if

$$\log \frac{1}{t} < \sigma(t) < \left(\frac{1}{t}\right)^\Delta$$

$$\text{and} \quad \rho(t) < t \sqrt{\sigma''(t)}$$

where  $\Delta$  is any positive big number

By the application of the theorem of Riemann-Lebesgue, we get the following criterion<sup>2</sup> —

(F) The Fourier series will be summable  $(c, 1)$ , if the integral

$$\int_0^b \left| \frac{\Phi(t)}{t^2} \right| dt$$

exists

We give below an example in which the above criterion is applicable, although the  $\lim_{t \rightarrow 0} \Phi(t)/t$  does not exist

Example Let

$$\Phi(t) = \frac{\sin^2 \left\{ n^4 \left( t - \frac{1}{n^2} \right) \pi \right\}}{n^2} \quad \left( \frac{1}{n^2} \leq t \leq \frac{1}{n^2} + \frac{1}{n^4} \right),$$

and  $\Phi(t) = 0$  elsewhere

Then  $\phi(t) = \Phi'(t)$  is integrable, and so

$$\Phi(t) = \int_0^t \phi(u) du$$

$$\text{Also} \quad \int_{\frac{1}{n^2}}^{\frac{1}{n^2} + \frac{1}{n^4}} \left| \frac{\Phi(t)}{t^2} \right| dt < \frac{1}{n^2} \int_{\frac{1}{n^2}}^{\frac{1}{n^2} + \frac{1}{n^4}} \frac{dt}{t^2} < \frac{1}{n^2}$$

<sup>1</sup> Du Bois-Reymond, 3, 37, also see Hardy, 6, 259

<sup>2</sup> Pollard has obtained a similar criterion for the Denjoy-Fourier series See Pollard 12

so that the integral

$$\int_0^{\delta} \left| \frac{\Phi(t)}{t^{\frac{1}{2}}} \right| dt$$

exists, but  $\Phi(t)/t$  does not tend to any definite limit as  $n$  tends to zero.

It may be mentioned that the criteria (F) and (C) are quite independent of each other, as may be easily verified by means of suitable examples. Thus for

$$\phi(t) = \frac{1}{2} t^{\frac{1}{2}} \sin \frac{1}{t} - \frac{1}{t^{\frac{1}{2}}} \cos \frac{1}{t}$$

the criterion (F) is satisfied but not (C). Again for

$$\phi(t) = \left( \log \frac{1}{t} \right)^{-1},$$

(C) holds, but not (F).

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# NOTES ON BESSEL FUNCTIONS

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The object of the present note is to evaluate several infinite integrals involving Bessel Functions of order zero. It is believed that most of these results have not been published before

1 We have the integrals<sup>1</sup>

$$\int_0^{\infty} y J_0(2xy) \cos\left(\frac{y^2}{k}\right) dy = \frac{1}{2} k \sin kx^2, \quad (1)$$

and

$$\int_0^{\infty} y J_0(2xy) \sin\left(\frac{y^2}{k}\right) dy = \frac{1}{2} k \cos kx^2 \quad (2)$$

We shall take these two integrals as the starting point and deduce a number of interesting integrals

In (2), let us divide both members by  $k$  and put  $k = \cosh \theta$  Integrating\* with respect to  $\theta$  from zero to infinity, we get

$$\begin{aligned} \int_0^{\infty} \int_0^{\infty} y J_0(2xy) \sin(y^2 \operatorname{sech} \theta) \operatorname{sech} \theta d\theta dy \\ = \frac{1}{2} \int_0^{\infty} \cos(x^2 \cosh \theta) d\theta \\ = -\frac{\pi}{4} Y_0(x^2) \end{aligned}$$

But

$$\int_0^{\infty} \sin(y^2 \operatorname{sech} \theta) \operatorname{sech} \theta d\theta$$

\* The change in the order of integration can be easily justified

becomes

$$\int_0^{\frac{\pi}{2}} \sin(y^2 \cos x) dx,$$

by virtue of the substitution

$$\tan^{-1}(\tanh \frac{1}{2} \theta) = \frac{1}{2} x,$$

and the latter integral is equal to  $\frac{\pi}{2} H_0(y^2)$ , where  $H_0(x)$  represents Struve's function of order zero<sup>2</sup>

Therefore we have<sup>4</sup>

$$\int_0^{\infty} y J_0(2xy) H_0(y^2) dy = -\frac{1}{2} Y_0(x^2) \quad (3)$$

If we proceed with the first integral as before, we are able to deduce that<sup>4</sup>

$$\int_0^{\infty} y J_0(2xy) J_0(y^2) dy = \frac{1}{2} J_0(x^2) \quad (4)$$

Again in (2), let us put  $k=1$  and multiply both members by  $\frac{x}{(x^4+4a^4)^{\frac{1}{2}}}$ . Integrating both sides with respect to  $x$  from zero to infinity we get

$$\begin{aligned} & \int_0^{\infty} \int_0^{\infty} xy J_0(2xy) \frac{\sin y^2}{(x^4+4a^4)^{\frac{1}{2}}} dx dy \\ &= \frac{1}{2} \int_0^{\infty} x \cos \frac{x^2}{(x^4+4a^4)^{\frac{1}{2}}} dx = \frac{1}{2} K_0(2a^2) \end{aligned}$$

But the left hand side can easily be shown to be equal to

$$\int_0^{\infty} y J_0(2ay) K_0(2ay) \sin y^2 dy$$

We therefore arrive at the result<sup>5</sup>

$$\int_0^{\infty} y J_0(2ay) K_0(2ay) \sin y^2 dy = \frac{1}{2} K_0(2a^2) \quad (5)$$

In a similar manner we can prove the following results,

$$\int_0^{\infty} y J_0(2ay) K_0(2ay) \cos y^2 dy = \frac{\pi}{8} [I_0(2a^2) - L_0(2a^2)]$$

where  $L_0(x)$  bears the same relation to  $H_0(x)$  as  $I_0(x)$  bears to  $J_0(x)$ . (6)

$$\int_0^{\infty} y I_0(ay) K_0(ay) \sin y^2 dy = \frac{\pi}{8} \left[ \sin \frac{1}{2} a^2 I_0\left(\frac{1}{2} a^2\right) - \cos \frac{1}{2} a^2 Y_0\left(\frac{1}{2} a^2\right) \right], \quad (7)$$

$$\int_0^{\infty} x J_0(2ax) K_0(2ax) H_0(x^2) dx = \frac{1}{4\pi} K_0^2(a^2), \quad (8)$$

$$\int_0^{\infty} y K_0(2ky) J_0(y^2) dy = \frac{\pi}{8} [H_0(k^2) - Y_0(k^2)], \quad (9)$$

$$\int_0^{\infty} y J_0(2ky) K_0(2ky) J_0(y^2) dy = \frac{1}{4} I_0(k^2) K_0(k^2), \quad (10)$$

$$\int_0^{\infty} [I_0(2a^2 \cosh \theta) - L_0(2a^2 \cosh \theta)] d\theta = I_0(a^2) K_0(a^2) \quad (11)$$

2 The Bessel-Fourier theorem states that with certain restrictions which are not important, a function  $f(\rho)$  can be expressed by the double-integral

$$f(\rho) = \int_0^{\infty} \int_0^{\infty} xy J_n(x\rho) J_n(xy) f(y) dx dy \quad \text{where } n > -\frac{1}{2}$$

$$\text{Let } n=0 \text{ and } f(y) = \frac{1}{(y^2 + 4k^2)^{\frac{1}{2}}}$$

We get

$$\int_0^{\infty} x J_0(x\rho) I_0(xk) K_0(xk) dx = \frac{1}{(\rho^2 + 4k^2)^{\frac{1}{2}}} \quad (11')$$

Now multiply both members of (10) by  $k J_0(k\rho)$  and integrate with respect to  $k$  from zero to infinity

We get

$$\begin{aligned} \int_0^{\infty} \int_0^{\infty} ky J_0(k\rho) J_0(y^2) J_0(2ky) K_0(2ky) dk dy \\ = \frac{1}{4} \int_0^{\infty} k J_0(k\rho) I_0(k^2) K_0(k^2) dk \end{aligned}$$

But the double integral is seen to be equal to

$$\int_0^{\infty} \frac{y J_0(y^2) dy}{(\rho^4 + 64 y^4)^{\frac{1}{2}}} \\ = \frac{1}{16} I_0\left(\frac{\rho^2}{16}\right) K_0\left(\frac{\rho^2}{16}\right)$$

Hence writing  $4\rho$  for  $\rho$ , we have

$$\int_0^{\infty} k J_0(4k\rho) I_0(k^2) K_0(k^2) dk = \frac{1}{4} I_0(\rho^2) K_0(\rho^2) \quad (12)$$

Similarly we have

$$\int_0^{\infty} x J_0(2x\rho) [H_0(x^2) - Y_0(x^2)] dx = \frac{1}{2} [H_0(\rho^2) - Y_0(\rho^2)]. \quad (13)$$

Whence taking into account the relation (3), we get

$$\int_0^{\infty} x J_0(2x\rho) Y_0(x^2) dx = -\frac{1}{2} H_0(\rho^2) \quad \dots \quad (14)$$

A similar procedure gives the result

$$\frac{\pi}{2} \int_0^{\infty} x J_0(x\rho) [I_0(\frac{1}{2}x^2) - L_0(\frac{1}{2}x^2)] dx = K_0(\frac{1}{2}\rho^2), \quad (15)$$

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# ON THE ABSORPTION SPECTRUM OF HYDROGEN PEROXIDE VAPOUR

By R S SHARMA

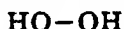
PHYSICS DEPARTMENT, UNIVERSITY OF ALI AHABAD

Communicated by Prof M N Saha

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Hydrogen peroxide is in many respects an anomalous chemical substance. It has generally strong oxidizing properties, but in several reactions, it acts as a reducing agent also. For example, the peroxide reduces ozone to oxygen, silver oxide to silver and lead dioxide to lead monoxide. This reducing property is, however, only apparent. It is due to the fact, that the peroxide molecule readily parts with one oxygen atom which oxidises one oxygen atom in ozone, etc, the result being that both the reacting substances, *viz*, the peroxide and ozone, etc, are reduced. This dual nature of hydrogen peroxide requires that both the oxygen atoms should not be symmetrically placed in the molecule. There are two alternative views about the constitution of the peroxide molecule

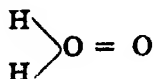
According to one view the constitution is



or



While according to second view it is



2343/6

For some time past workers in this laboratory have been studying the absorption spectra of various substances with a view to investigate the constitution and the nature of the force of binding in molecules. Very little work has, however, been done on the absorption spectrum of hydrogen peroxide vapour, although extensive work has been done with its solution in water. The work of Elder & Rideal<sup>1</sup> shows that the thermal decomposition of its vapour is mostly a surface action. Urey, Dawsey and Rice<sup>2</sup>, however, have made an extensive study of the absorption spectra of its vapour and they find that there is a continuous absorption beginning at about 3000Å. They have further found that there is no trace of any band structure in the absorption spectrum. The fluorescence spectrum of its vapour, when it is illuminated with zinc spark

lines 2025Å to 2130Å, shows the well known water band at  $\lambda$  3064 (0,0) which is associated with the OH molecule. Taking all this evidence into consideration they have come to the conclusion that the constitution of  $H_2O_2$  is  $HO-OH$ , i.e.  $F_2$  like, and the action of light on the molecule is as follows —



In the present paper results of certain experiments on the action of light on the vapour of hydrogen peroxide are reported. The absorption spectrum has been studied in the ultra-violet region down to the limit of absorption of the atmosphere, while Urey and his co-workers confined their work up to  $\lambda$ 2150. No attempt has, however, been made to measure the absorption coefficients. This has been very exhaustively done by Urey, Dawsey and Rice and it was thought that no improvement could be made on their work. An alternative suggestion for the photo-chemical dissociation of the peroxide molecule has, however, been put forward. This is based on the

assumption that the structure of the peroxide molecule is  $\begin{array}{c} H \\ \diagup \\ O \\ \diagdown \\ H \end{array} = O$

Two supplementary experiments have also been reported and they lend some support to the new point of view.

An attempt was made to study the recombination spectrum of hydrogen peroxide vapour. It may be thought that if the products of photo-dissociation recombined there will be an emission of energy corresponding to the heat of reformation. Thus we may expect a continuous spectrum beginning at a long wavelength limit and extending some distance towards the violet. This has been found to be the case.

### EXPERIMENTAL

Three different samples of hydrogen peroxide were used in the study of the absorption spectra, viz., 3%, 10% and 30% solutions supplied by Merck. The last is ordinarily known as perhydrol. The absorption chamber was a glass tube one centimeter in diameter having a length of 180 cms. The two ends of the tube were closed with quartz windows. The solution was contained in a bulb which was connected to the absorption chamber by a side tube. Another opening led to a pump which was kept running continuously. The continuous running of the pump served two purposes. Firstly it kept the pressure inside the absorption chamber low (about 2 or 3 mms.), thus removing water vapour and concentrating the peroxide solution progressively. The vapour pressure of the peroxide at the temperature of the absorption chamber, i.e., at 20°C

is 15 mms. while that of water is 174 mms. The second advantage is that there is a fresh supply of vapour in the absorption chamber thus renewing the vapour which is reduced by the action of light

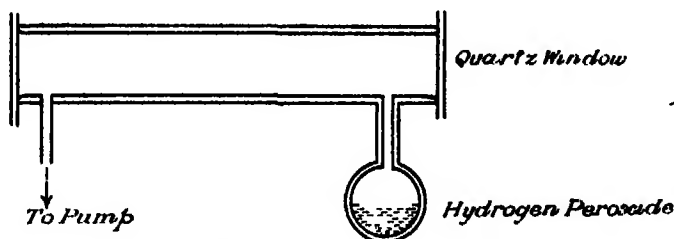


Fig 1

For continuous light a Hydrogen tube run by a 2 K W transformer was used. Photographs were taken with a quartz E, spectrograph. Schumann plates were used for photographing the spectra. A copper arc was used as a standard.

The second part of the experiment consisted in studying the recombination spectrum of the peroxide vapour when it is illuminated with light of sufficiently short wavelength. A sketch of the apparatus used is given below.

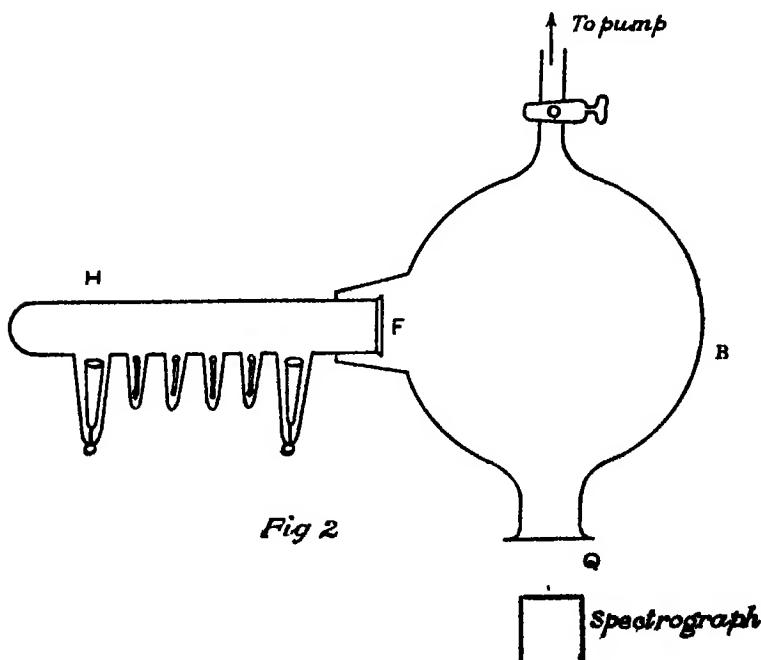


Fig 2

A Hydrogen tube H with a fluorite window F is sealed to a glass bulb B. At right angles to the length of the hydrogen tube is another opening which is closed with a quartz window Q. A side tube leads to a pump.

The inside of the bulb was thoroughly cleaned and was then rinsed with hydrogen peroxide. Next a small quantity of perhydrol was introduced in the bulb and the window was closed with the quartz plate Q. The bulb was then evacuated by a pump so that the pressure inside was a few mms. The stop-cock was then closed. The pump was run at intervals throughout the whole period of exposure. The bulb was covered on all sides to prevent any stray external light in the dark room from entering the bulb. The Hydrogen tube was run by a 2 K W transformer and exposure was taken through the window Q with a quartz spectrograph. The time of exposure was 40 hours. Another check exposure of the same duration, with the bulb empty, was also taken to test if the recombination spectra is really genuine and not due to internal reflection.

## RESULTS AND DISCUSSIONS

The results of this investigation are as follows —

1 The absorption spectrum shows a sharp cut at  $2055\text{\AA}$

This corresponds 139 kcal.

2 The recombination spectrum shows a continuous patch of light beginning at about  $4800\text{\AA}$  and extending to about  $3900\text{\AA}$

I shall now try to interpret these results in the light of Urey's model. We suppose that the constitution of the peroxide molecule is  $\text{HO}-\text{OH}$  or  $\text{F}_2$  like. But the absorption spectrum of  $\text{F}_2$  consists of bands followed by continuous absorption from a long wavelength limit which marks its splitting into  $\text{F}(^3\text{P}_2) + \text{F}(^3\text{P}_2)$ . In the case of  $\text{H}_2\text{O}_2$ , we get no bands in absorption. Hence the Franck-Condon diagrams should be as in figure 3.

The normal state of the molecule is represented by the curve L. By the absorption of light it passes from the point B in the curve L to the point C in the curve M which represents the next higher state of the molecule. This curve has no minimum. The molecule will therefore dissociate into  $\text{OH}(^3\Pi_2) + \text{OH}(^3\Pi_2)$ . The molecule may, however, also

pass to the point D in the second higher curve N and may dissociate into  $\text{OH}(^2\Pi_{3/2}) + \text{OH}(^2\Sigma)$ . The energy of excitation of the  $\lambda$  3064 (0, 0) band

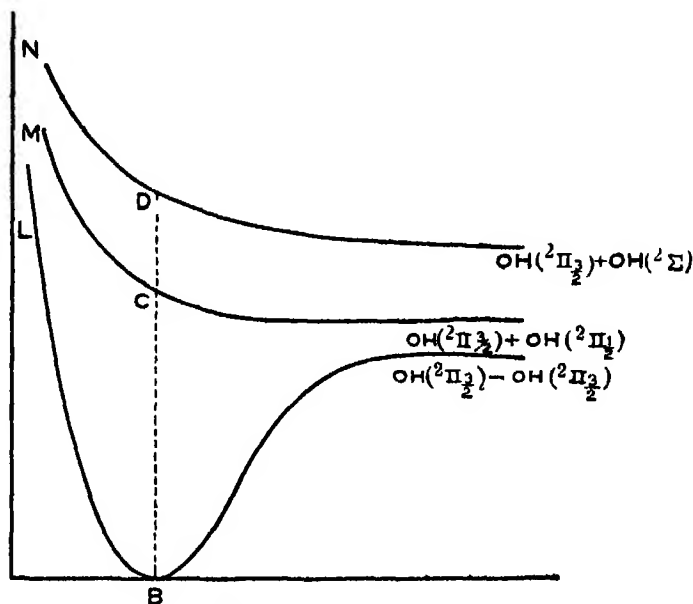
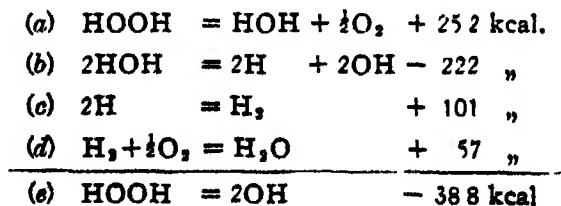


Fig 3

which is due to the excitation of OH from  $(^2\Pi_{3/2})$  to  $^2\Sigma$  is 93.4 kcal. Hence supposing that the cut observed by me at  $\lambda$  2055 corresponds to the dissociation in the state D the heat of dissociation of  $\text{H}_2\text{O}_2$  into two normal OH molecules is  $139.1 - 93.4 = 45.7$  kcal.

But it can be shown that this does not agree with the value of the heat of dissociation obtained from other data. This can be approximately found as follows.—

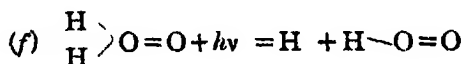


The thermo-chemical figures involved in (a) have been taken from the tables of Landolt and Börnstein. Those in (b) have been given by

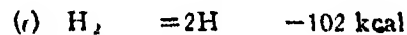
Bonhoeffer and Reichart<sup>3</sup> and Bonhoeffer and Haber<sup>4</sup>. The heat of formation of  $H_2O$  given in (d) has been taken from Frankenburger and Klinkhardt<sup>5</sup>

The disagreement between this value, *viz.*, 38 kcal and that obtained from absorption experiments, *viz.*, 45.6 kcal is appreciable

Passing on now to the other constitutional formula for the peroxide molecule, *viz.*  $\begin{smallmatrix} H \\ | \\ H \end{smallmatrix} O=O$  the possible photo-chemical reactions are as follows —



The energy corresponding to the reaction (f) cannot be calculated, but that involved in (g) can be easily found as follows —

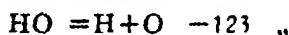


The thermo-chemical data in (h) is taken from Urey's<sup>2</sup> paper. The heat of dissociation of  $H_2$  is taken as 102 kcal<sup>6</sup>

The energy value 136 kcal that we get from (j) almost correspond to the continuous absorption at  $2055\text{\AA}$  obtained in the present investigation

On this view there should be a second absorption corresponding to the photo-chemical reaction in (f). Now Urey and his co-workers have taken the beginning of absorption to be at  $3000\text{\AA}$  from the measurement of absorption coefficients. They have, however, remarked that the absorption by vapour might begin much earlier (towards the red side), almost at the same place as the absorption by the aqueous solution of  $H_2O_2$ , *viz.*, at  $3750\text{\AA}$ . The recombination spectrum in the present investigation which begins at  $4800\text{\AA}$  can be interpreted as being due to the emission of energy when the products of photo-chemical reaction (f) recombined to form the  $H_2O_2$  molecule. The energy value corresponding to  $4800\text{\AA}$  is 59.6 kcal. This is then the energy required to remove the first hydrogen atom from the peroxide molecule. This is not an unlikely value, for in the case of  $H_2O$  molecule we know that the

removal of the first hydrogen atom requires a little less energy than half the energy required to remove both the hydrogen atoms. This is shown below<sup>4</sup> —



To test the presence of atomic hydrogen (if our point of view of the photo-chemical dissociation of the peroxide vapour be correct) a small piece of cupric oxide was placed in the absorption chamber. The vapour was then illuminated with carbon arc light which gives the strong carbon line  $\lambda 1931$ . The cupric oxide acquired a slight reddish tinge. This may be due to the reduction of the cupric to the cuprous oxide.

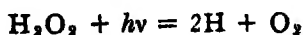
Besides if the constitution of  $\text{H}_2\text{O}_2$  is  $\text{HO}-\text{OH}$ , i.e.,  $\text{F}_2$  like, it should have no electric moment as the electric moment of the halogen molecules is zero. Linton and Maas<sup>7</sup> have recently determined the electric moment of  $\text{H}_2\text{O}_2$ . They find it to be  $2.13 \times 10^{-18}$  units at  $25^\circ\text{C}$ . The electric moment<sup>8</sup> of  $\text{H}_2\text{O}$ , as they find it, is  $1.90 \times 10^{-18}$  units and is of the same order of magnitude as that of  $\text{H}_2\text{O}_2$ . These authors are therefore inclined to the view that the constitution of  $\text{H}_2\text{O}_2$  is  $\text{H}_2\text{O}=\text{O}$ . This agrees with our conclusion.

### SUMMARY

1. The absorption spectrum of hydrogen peroxide vapour shows a sharp continuous absorption beginning at  $2055\text{\AA}$ . This corresponds to  $139.1 \text{ kcal}$ .

2. The recombination spectrum shows a continuous emission of light beginning at  $4800\text{\AA}$ . This corresponds to  $59.6 \text{ kcal}$ .

3. The sharp cut at  $2055\text{\AA}$  is interpreted as due to the following photo-chemical dissociation —



$$\text{where } h\nu = 136.1 \text{ kcal}$$

4. The recombination spectrum is interpreted as to be due to the energy emitted in the process —



5. The slight reduction of cupric oxide lends some support to the view that atomic hydrogen is formed in the photo-chemical dissociation of the peroxide vapour.

My best thanks are due to Prof M N. Saha, F.R S, for his kind interest and guidance in this work

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# THE APPLICATION OF FRANCK CONDON PRINCIPLE TO CONTINUOUS ABSORPTION SPECTRA OF DIATOMIC MOLECULES

BY HRISHIKESHA TRIVEDI

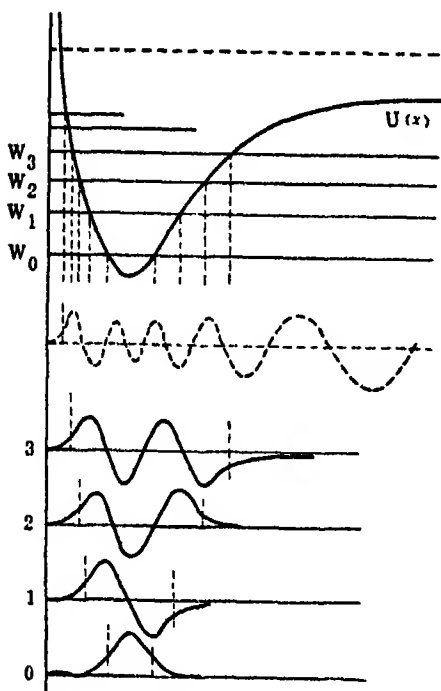
PHYSICS DEPARTMENT, ALLAHABAD UNIVERSITY

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Much experimental work has been done recently on the continuous absorption spectra of various molecular compounds. Franck and his co-workers<sup>1</sup> mostly confined their attention to the point of maximum absorption. Attention to the importance of the beginning of absorption was first drawn by workers in this laboratory. These observations were applied to the determination of the energies of dissociation of the molecules from the value of the initial absorption frequency. The process of optical dissociation, which gives rise to such a spectrum, is supposed to be governed by Franck's principle. According to this principle, in the act of absorption of light quanta, the electron passes to the higher level so quickly that the vibration and rotation terms are not affected at all. Condon<sup>2</sup> has attempted to give a picture of this principle. According to him the process of optical dissociation can best be understood by considering curves showing the variation of the potential energy of the components with the distance between them (internuclear distance). At all points of this potential energy curve the molecule will have the same electronic energy. The state of vibration of the molecule is represented by drawing horizontal lines the heights of which above the abscissa axis represent the energy of vibration of various states. The vibration  $\psi$  function for any stable di-atomic molecule in a particular electronic state was found by Condon<sup>2</sup> and Hutchisson<sup>3</sup> to have a maximum value at those points where the above mentioned horizontal lines cross the potential energy curve (Fig. 1). In accordance with Franck's hypothesis, that the distance is not changed in the act of absorption, Condon represented the transitions from one electronic state of the molecule to its another electronic state brought about by the absorption of light by vertical arrows. These

arrows originated from points of maximum value of the vibration



Eigen-values and Eigen-functions of a typical system with one degree of freedom (Smeke's Quanten theorie, S. 570)

Fig. 1

the order of magnitude involved is approximately equal to the interval on the frequency scale given by "reflecting" the initial state vibration wave-function in the potential energy curve of the final state. Condon considers the zero state to be non-vibrating and therefore assumes that its wave-function is represented by a Gauss error curve\*

\*It is proved in Wave-mechanics that the wave-function of a linear oscillator (vibration quantum number  $n$ ) is given by

$$\psi_n = e^{-\frac{x^2}{2}} H_n(x)$$

$$\text{where } x = r/\bar{b}, \quad \bar{b} = \frac{16\pi^2\nu_0}{h^2}$$

and  $H_n(x)$  are the Hermite functions defined as

$$H_n(x) = (-1)^n e^{x^2} \frac{d^n}{dx^n} e^{-x^2}$$

$$\text{for } n=1, \quad H_1(x) = 2x$$

Hence  $\psi_0$  = Gaussian error curve,

$\psi$  function of the lower electronic state. This application of Franck's principle by Condon was found to be very much successful in the case of band spectra of di-atomic molecules. According to Condon, those transitions should be most intense for which the maxima of  $\psi$  functions in the two states coincided. Experimental results confirmed this, although there are exceptions.

The variation of intensity in the continuous absorption spectrum of a di-atomic molecule was also explained by Condon on these very lines. The molecules considered were the halogens. Condon tests the validity of his method as applied to continuous spectra by examining if his method gave the right order of magnitude for the breadth of the continuous band indicating the dissociation of a molecule. According to him

The actual procedure adopted by Condon in the operation which he calls "reflection" seems to be one given by figure 2. Vertical lines are drawn from the various points A, B, C, D, E on the Gauss error curve 1, so as to touch the upper potential energy curve, wherefrom horizontal

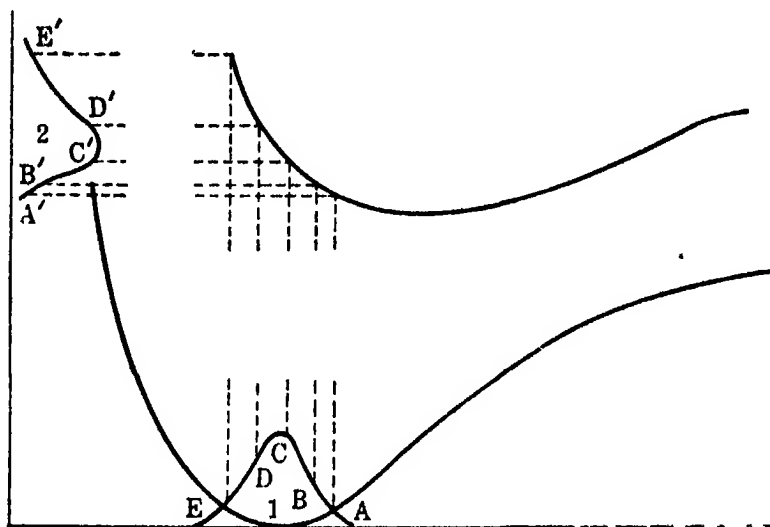


Fig 2

lines are drawn so as to cross the axis of Y. On these lines are marked points whose distances from the Y axis is just the same as are those of the corresponding points A, B, C, D, E on the Gauss error curve 1 from the X axis. This curve 2 is roughly similar to the curve 1, and as Condon takes A' E' to be the width of the continuous absorption band in the wave number scale marked along the Y axis, the curve 2 represents the transitional probabilities from the lower state to the upper one.

The assumption of Condon that the zero state is non-vibrating does not, however, always correspond to the experimental conditions. The temperatures at which the experiments have been conducted to determine the intensity of continuous absorption band are such that a considerable fraction of molecules may pass to higher vibrational states. For such states, the wave-function will not be a Gauss error curve but one with at least two maxima ( $n=1$ ). Taking up the same line of argument as Condon did in the case where the vibration wave function was a Gauss error curve (zero vibration level) it can be easily seen that the transition probabilities from the lower to the upper state will be given by a curve having two maxima, when the molecules in the lower state are in the

first vibration level and correspondingly when the vibration wave-function of the lower state is not a Gauss error but a curve with two maxima (*cf* Fig 1) The absorption spectrum will, therefore, have two maxima separated by a region where the absorption is smaller than on either side of it. Such a state of affairs has not been traced

It may be remarked at this stage that there are certain types of continuous absorption spectra which have a fluctuation in their intensities at the long wavelength beginning They have been classified by Finckelburg<sup>4</sup> under class II There has been observed yet another kind of continuous absorption spectrum with fluctuations of intensity at the long wavelength beginning of it by Sommermeyer<sup>5</sup> in the case of some alkali halides The fluctuations are very gradual and wide It can, however, be seen very easily that the intensities of both these types of absorption spectra cannot be obtained when the vibration wave-function of the lower state possessing several maxima (vibration quantum number high) (*cf* Fig 1) is reflected in the upper wave-function The actual process of reflection shows that if the intensity fluctuation is not to be wider than what is observed, the upper potential curve is to be flat and the fluctuation will extend all over the length of the continuous absorption spectrum which itself will not be very wide Experiments show us, however, that the intensity fluctuation is only at the long wavelength beginning of the absorption spectra, which in itself is sufficiently wide in the case of Finckelburg's class II spectra, and passes outside the region investigated in the case of alkali halides We can thus see that such fluctuations in the intensity of an absorption spectrum cannot be explained by the application of Condon's method

This disagreement between theory and experiment may be explained in the following way The left side of the upper curve may be so steep that the ultra-violet end of the spectrum may fall outside the region which is available for investigation, so that Condon's process will give us an absorption spectrum which actually corresponds to facts

In accepting this explanation, however, we will have to consider one thing The beginning of the absorption corresponds tolerably well to the heat of dissociation of practically all the di-atomic molecules so far investigated as determined thermochemically or by any other reliable means This fact requires the upper curve to be very nearly horizontal from the point P vertically above the beginning of the first maximum of the vibration wave-function of the lower curve (Fig 3) In order to make it compatible with the above-needed steepness of the upper curve we have to make either of the following assumptions. First, the upper curve

suddenly becomes steep to the left of the point P. Secondly, if the curve does not become steep suddenly to the left of P we take Condon's principle to be invalid, for it was only for keeping it valid and still to explain the extension of the continuous spectrum to infinity that we had to suppose that the curve suddenly became steep to the left of P. Thirdly, we can suppose the upper curve to have very nearly the same slope throughout and disregard the assumptions according to which the curve beyond P is horizontal. If we assume the third alternative the energy which corresponds to the beginning of absorption cannot give the heat of dissociation of the molecule.

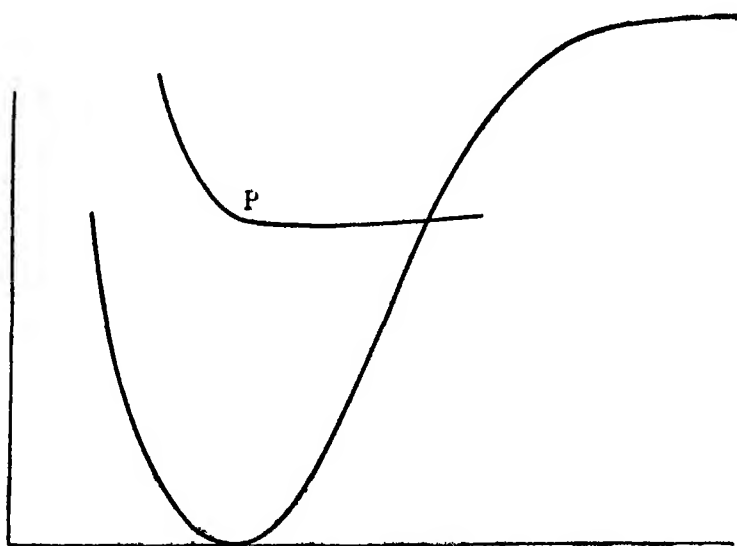


Fig 3

In the state of the molecule which is represented by the upper curve we have as yet no knowledge of any molecular force which will make the slope of the curve to be changed by such a degree and such a suddenness at a particular point P. It would be much safe to assume that there is no such transition to the steep slope of the curve. If we drop the explanation for which the steepness had to be introduced we are forced to the possibility that Condon's procedure is invalid for many cases of continuous absorption spectra of di-atomic molecules. If, however, we reject the explanation which necessitates the upper curve to be horizontal beyond P we let the very reliable and very plausible work of Franck<sup>1</sup> and his school fall flat to the ground. The results obtained by Franck

and his co-workers in interpreting the continuous absorption in terms of the energy of dissociation of the molecule are so many and of such a quantitative precision as to merit their parent theory being taken to be true

The aim of the present paper is to land us out of this quagmire. To do this the following procedure will be adopted. There are various kinds of continuous spectra observed in molecules. Finckelnburg<sup>4</sup> has classified them in six different classes. It is the purpose of this communication to deal with homogeneous continuum which remains purely continuous even if the temperature and pressure of the absorbing gas varies. This has been classified by Finckelnburg as class I. As this type of spectra is obtained mostly in absorption the obvious conclusion is that the molecules are extremely unstable in the upper state, and the binding forces will be only repulsive ones.

Such a repulsive potential has been computed for atomic hydrogen,<sup>6</sup> helium,<sup>7</sup> and for molecules.<sup>8</sup> It appears possible to represent it in the range of importance in the mutual repulsion of the atoms by the approximate formula

$$A + D e^{-2ar}$$

where A, D and  $a$  are constants,  $r$  the nuclear distance and  $e$  the base of logarithm

The next step to be taken is the calculation of the wave-function for the unstable state of the molecule. The wave equation of the molecule is as follows

$$\Delta \psi + \frac{8\pi^2\mu}{h^2} (E - V) \psi = 0 \quad \dots \quad (1)$$

where  $E$  = energy constant,  $V$  = potential energy expressed as a function of the coordinates

Considering it to be a problem of boundary values with spherical symmetry and introducing polar coordinates  $r, \theta, \phi$ , we obtain from equation (1)

$$\frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial \psi}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial \psi}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \psi}{\partial \phi^2} + \frac{8\pi^2\mu}{h^2} (E - A - D e^{-2ar}) \psi = 0 \quad \dots \quad (2)$$

where  $\mu$  = reduced mass.

Integrating this equation by the method of separation of variables, we set

$$\psi = R(r) \theta(\theta) \varphi(\phi)$$

Considering first  $\varphi(\phi)$  we see that, as it does not occur explicitly in the equation (2)

$$\varphi(\phi) = e^{+im\phi}$$

The postulate of uniformity leads to the integral values of  $m$

Substituting this value of  $\varphi$  in (2) and considering  $\theta(\theta)$  we get

$$\frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left\{ \sin \theta \frac{\partial \theta}{\partial \theta} \right\} + \left( \lambda - \frac{m^2}{\sin^2 \theta} \right) \theta = 0$$

where  $\lambda$  is a constant  $= n(n+1)$ ,  $n$  being a positive integer. We get therefrom

$$\theta(\theta) = P_n^m(\cos \theta)$$

Now let the term containing  $r$  in the equation (2)

$$\text{be } \frac{1}{r} - \frac{\partial^2}{\partial r^2} (r\psi)$$

$$\text{We now set } r\psi = F \cdot P_n^m(\cos \theta) \cdot e^{+im\phi}$$

As the final state is continuous, the  $m$  in the above expression, denoting the rotational quantum number, can be placed equal to zero, therefore

$$r\psi = F \cdot P_n^0(\cos \theta)$$

whence we get the wave-equation

$$\frac{d^2 F}{dr^2} + \frac{8\pi^2 \mu}{h^2} (W - D e^{-2ar}) F = 0 \quad \dots \quad (3)$$

where  $W = E - A$

Making a transformation  $y = e^{-ar}$ , we have

$$\frac{dF}{dr} = \frac{dF}{dy} \frac{dy}{dr} = \frac{dF}{dy} (-a e^{-ar})$$

$$\frac{d^2 F}{dr^2} = \frac{d^2 F}{dy^2} \cdot \frac{dy}{dr} \cdot (-a e^{-ar}) + a^2 e^{-ar} \frac{dF}{dy}$$

whence equation (3) is transformed to

$$a^2 y^3 \frac{d^2 F}{dy^2} + a^2 y \frac{dF}{dy} + \frac{8\pi^2 \mu}{h^2} (W - Dy^2) F = 0 \quad (4)$$

$$\text{or} \quad \frac{d^2 F}{dy^2} + \frac{1}{y} \frac{dF}{dy} + \frac{8\pi^2 \mu}{a^2 h^2} (W - D) F = 0 \quad (5)$$

According to the meaning of  $r$  the boundary points of the region in  $y$  are the values  $y=0$  and  $y=\infty$ . We can easily see that  $y=0$  is a pole

Schrodinger's<sup>9</sup> criterion for  $F$  as determined by equation (5) is that it will be finite and single-valued throughout the space. For the problem of finding the solution which remains finite everywhere, it is necessary to see that the solution is finite at the points of singularity for the differential equation.

The equation (5) takes the form

$$y^2 \frac{d^2 F}{dy^2} + y \frac{dF}{dy} + \frac{8\pi^2 \mu}{a^2 h^2} (W - Dy^2) F = 0 \quad (6)$$

Putting

$$\frac{8\pi^2 \mu D}{a^2 h^2} = -\lambda^2, \quad \lambda y = x,$$

and

$$\frac{8\pi^2 \mu W}{a^2 h^2} = -v^2$$

we get the equation (6) as

$$x^2 \frac{d^2 F}{dx^2} + x \frac{dF}{dx} + (x^2 - v^2) F = 0 \quad \dots \quad (7)$$

Let us now construct a solution of (7) which is valid near  $y=x=0$ , the form assumed for such a solution is a series of ascending powers of  $x$ , say

$$F = \sum_{m=0}^{\infty} C_m x^{\alpha+m}$$

where the index  $\alpha$  and the coefficients  $C_m$  are to be determined, with the proviso that  $C_0$  is not zero.



For brevity the differential operator which occurs in (7) will be called  $\nabla_v$ , so that

$$\nabla_v \equiv x^2 \frac{d^2}{dx^2} + x \frac{d}{dx} + x^2 - v^2$$

It can be seen easily that

$$\nabla_v \sum_{m=0}^{\infty} C_m x^{a+m} = \sum_{m=0}^{\infty} C_m \{(\alpha+m)^2 - v^2\} x^{a+m} + \sum_{m=0}^{\infty} C_m x^{a+m+2}$$

The expression on the right reduces to the first term of the first series, namely,  $C_0 (\alpha^2 - v^2) x^a$ , if we choose the coefficients  $C_m$  so that the coefficients of corresponding powers of  $x$  in the two series on the right cancel

This choice gives the system of equations

$$\begin{aligned} C_1 \{(\alpha+1)^2 - v^2\} &= 0 \\ C_2 \{(\alpha+2)^2 - v^2\} + C_0 &= 0 \\ C_3 \{(\alpha+3)^2 - v^2\} + C_1 &= 0 \\ &\vdots \\ C_m \{(\alpha+m)^2 - v^2\} + C_{m-2} &= 0 \end{aligned} \quad (8)$$

From this result it is evident that the postulated series can be a solution of (7) only if  $\alpha = \pm v$ , for  $C_0$  is not zero, and  $x^a$  vanishes only for exceptional values of  $x$ . We must further take  $\alpha = +v$  in order that  $\Psi$  may be finite for  $x=0$ , when  $v$  is a positive quantity

It can now be very easily seen that

$$C_0 x^v \left[ 1 + \sum_{m=1}^{\infty} \frac{(-1)^m (\frac{1}{2} x)^{2m}}{m! (v+1)(v+2)(v+3) \cdots (v+m)} \right] \quad (9)$$

is a formal solution of (7)

Any value independent of  $x$  may be assigned to the constant  $C_0$ . Putting it equal to  $1^0$

$$2^v \frac{1}{\Gamma(v+1)}$$

we get the series (9) in the form

$$\sum_{m=0}^{\infty} \frac{(-1)^m (\frac{1}{2} x)^{v+2m}}{m! \Gamma(v+m+1)} = J_v(x)$$

*NB*—All the  $v$ 's used above denote the same quantity, although at some places they appear different from the rest

This series is a solution of the equation (7) which is valid near  $y=x=0$  (the pole of the equation) for all values of  $x$  and for all positive values of  $v$

The series which defines  $J_v(x)$  converges absolutely and uniformly in any closed domain of values of  $x$ , and in any bounded domain of values of  $v$

When  $|v| \leq N$  and  $|x| \leq \Delta$ , the test ratio for this series is

$$\left| \frac{-\frac{1}{2}x^2}{m(v+m)} \right| \leq \frac{\frac{1}{2}\Delta^2}{m(m-N)} < 1$$

whenever  $m$  is taken to be greater than the positive root of the equation

$$m^2 - mN - \frac{1}{2}\Delta^2 = 0$$

This choice of  $m$  being independent of  $v$  and  $x$ , the result stated follows from the test of Weierstrass. Hence  $J_v(x)$  is an analytic function of  $x$  for all values of  $x$  and it is an analytic function of  $v$  for all values of  $v$ . Whence we can see that  $J_v(x)$  remains a finite quantity and is a solution of the equation (7) for all values of  $v$  and  $v$  changes its value continuously

In the famous equations solved by Schrödinger each one of them was solvable only when a particular parameter involving the total energy had certain discrete values. This restriction of the total energy having only certain discrete values was interpreted by him in terms of line or discrete band spectra. In the case under consideration the parameter  $v$  involving the total energy can have all values and always the wave-equation can be solved, therefore reasoning in an analogous way we can say that it represents continuous spectrum

This continuous spectrum begins where the value of  $v$  is equal to zero and extends onwards with its various positive values. When  $v=0$ ,  $W$  must also be equal to zero, i.e.,  $E-A$  must be equal to zero. The energy corresponding to  $A$ , being the heat of the dissociation of the molecule in that state, will in the Condon diagram be represented by the horizontal asymptote to the potential energy curve. The vertical height of this asymptote above the minimum position of the lowest state represents the heat of dissociation of the molecule in that excited state. The above consideration (i.e., the continuous spectrum begins at  $W=0$ ) shows that the continuous spectrum begins at this horizontal asymptote representing the heat of dissociation of the molecule in that excited state, no matter how much below it lies from the actual curve giving the relation between the potential energy of the molecule and its inter-nuclear distance, if we stick to the Condon diagram.

This fact provides us with the justification of Datta's<sup>11</sup> extrapolation of the curve relating the absorption coefficient with the wavelengths of the absorbed light which had previously appeared more or less *ad hoc*. He reached, thereby, to a beginning of absorption which corresponded to the heat of dissociation of the molecule. For we can easily see that there is no sense in the extrapolation unless there is a definite value of the vibration  $\psi$  function for the upper state different from zero for energies down to the heat of dissociation of the molecule.

Now we come to the representation of the process of the production of this continuous spectrum. Condon assumed that the transition took place only between two potential energy curves. There was to be no transition between any point lying on the lower potential energy curve and some other which did not lie on the upper potential energy curve. We have, however, seen above that the transition can be to a point which is lower than the nearest vertical on the upper curve. The extension of the continuous spectrum beyond that point to any value shows that points lying on the other side of the upper curve have also a transition probability to the lower curve. We are not justified, therefore, in forcing the points having a transition probability to the lower state to lie on a curve. They, on the contrary, seem to lie on a surface. The continuous spectrum which we observe is due to a transition from points on the lower curve lying on both sides of its minimum, where the vibration  $\psi$  function has maximum values, but we are not in a position to distinguish the portion due to each one of them. In fact it would be better not to regard this question in terms of potential energy curves but in terms of Schrödinger's equations for the various states of the molecule and their respective characteristic functions.

In order, therefore, to explain the continuous absorption by diatomic molecules we have not to make any more assumptions excepting the following. First, the upper repulsive curve is given by a formula of the type  $A + De^{-2ar}$ , an assumption which we have seen above to be justified. Secondly, the energy given by  $A$  is the energy of dissociation of the molecule in that state. All other postulates and assumptions seem unnecessary.

We shall deal with the various transition probabilities and the intensities to be expected in another communication.

#### ACKNOWLEDGEMENTS

It is the pleasant duty of the author to acknowledge his indebtedness to Prof. M. N. Saha, F.R.S., for his kindness on him and his interest in this work.

## SUMMARY

The homogeneous absorption spectrum of di-atomic molecules has been considered by Condon. Certain difficulties appear in that treatment. They have been pointed out. The problem is re-considered from the point of view of wave-mechanics. The potential energy of the molecule in the upper unstable electronic state is taken to be given by  $A + De^{-2ar}$ . A wave equation of the molecule for this state is formed and its solution shows that the  $\psi$  function has some value, different from zero, for all values of energy ( $E - A$ ) greater than zero, where  $E =$  energy constant. It is shown that the beginning of absorption gives the heat of dissociation of the molecule and the absorption will extend unrestricted to infinity.

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# THE QUANTUM ANALOGUE OF A THEOREM OF POISSON IN CLASSICAL DYNAMICS

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Received February 9, 1934

The discovery by Dirac of the quantum analogue of Poisson-bracket enables one to readily transform theorems in classical dynamics to the corresponding theorems in Quantum Mechanics. As one more (rather simple but elegant) illustration of this procedure we consider the following "classical" theorem of Poisson<sup>1</sup>. If  $\phi$  and  $\Psi$  are two integrals of a dynamical system, then the Poisson-bracket  $[\phi, \Psi]$  is constant throughout the motion, i.e., the equation  $[\phi, \Psi] = \text{constant}$  constitutes a new integral of the system. The proof of this important theorem in classical dynamics need not be reproduced here. The Quantum-mechanical proof is very simple.

Let  $\alpha$  and  $\beta$  be two observables that are constants of the motion, i.e.,  $\alpha$  and  $\beta$  commute with the Hamiltonian  $H$  but  $\alpha$  and  $\beta$  do not necessarily commute with each other.

Hence we have,

$$\alpha H - H\alpha = 0$$

$$\beta H - H\beta = 0$$

and therefore

$$\begin{aligned} & (\alpha\beta - \beta\alpha) H - H(\alpha\beta - \beta\alpha) \\ &= \alpha(\beta H - H\beta) + \beta(\alpha H - H\alpha) \\ &= 0 \end{aligned}$$

i.e., the expression  $(\alpha\beta - \beta\alpha)$  is also a constant of the motion. But  $(\alpha\beta - \beta\alpha)$  is the quantum definition of the Poisson-bracket  $[\alpha, \beta]$  and hence the above theorem is proved.

Let us consider an example. Suppose the components of angular momentum  $M_x$  and  $M_y$  are constants of the motion,

$$i\hbar, \quad M_x H - H M_x = 0$$

$$M_y H - H M_y = 0$$

Then, it follows from the theorem that  $[M_x, M_y]$  is also a constant of the motion. But from the well-known relation

$$\mathbf{M} \times \mathbf{M} = i\hbar \mathbf{M}$$

where  $\mathbf{M}$  is the angular momentum vector, it follows that  $[M_x, M_y] = i\hbar M_z$  and hence  $M_z$  is also a constant of the motion

This result is what one would expect from classical analogy

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# CHEMICAL EXAMINATION OF *PUNAR-NAVA* OR *BOERHAAVIA DIFFUSA*, LINN

By

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Received March 13, 1934

*Boerhaavia diffusa* known as Punar-nava in Sanskrit and Bengali, and Sant, Thikri or Gadhva-purna in Hindusthani, is a plant of the natural order Nyctaginæ. It is grown throughout India from Punjab to Assam and south to Travancore. It is diffusely branched herb, with rather thick leaves and white or red flowers, and grows profusely on barren lands, being a creeping weed.

As regards its medicinal properties Punar-nava has been mentioned by *Sushruta* and other older Sanskrit writers and hence is a plant of long medicinal use in India. "It is successfully used in jaundice, ascites, anasarca, scanty urine and internal inflammations," (Dutt). It is also used as a diuretic in gonorrhoea. It has always been used by the French and the Portuguese in all the above mentioned troubles with a marked success. If it is taken in sufficient doses it acts as a powerful emetic.

The chemical analysis of the plant was undertaken in 1910, and the following results were obtained<sup>1</sup> —

It contains (1) a sulphate of a body alkaloidal in nature, (2) an oily amorphous mass of the nature of fat (probably) and (3) sulphates, chlorides and traces of nitrates and chlorates from the ash. The amount of alkaloidal body is very small.

Dymock<sup>2</sup> mentions all the above properties of the drug and says that the whole plant was used for a chemical analysis and with the exception of minute traces of a principle soluble in ether and affording reactions with alkaloidal reagents nothing of interest was detected. No principle reacting with ferric salts was present. The above represents the work that has been done on this plant. On account of its high medicinal value the present authors were tempted to put it to a more systematic chemical examination. Unfortunately the so called 'alkaloidal' body supposed to be present in the plant could not be detected and hence the claims of the previous workers were not substantiated. However, as a result of investigation, it was found that the plant contains about 05% of a crystalline acid, 1% of potassium nitrate, 1.2% of a brown amorphous mass consisting mostly of tannins and phlobaphenes and reducing sugars (mainly glucose).

## EXPERIMENTAL.

The plant was collected from the neighbourhood in the month of October and dried for a month in the shade. The dried plant was then finely crushed in an iron mortar, and when burnt completely in a porcelain dish left 10.2% of a dirty white ash. The ash contained 74.8% of water insoluble and 25.2% of water soluble inorganic matter. The following elements and radicals were detected in the ash:—

Potassium, Sodium (traces), Magnesium, Calcium, Nitrates, Phosphates, Carbonates, Silica, and Sulphates (traces)

In order to ascertain the general characters of the soluble portion of the plant samples of finely powdered material were exhaustively extracted in a Soxhlet's apparatus using various solvents, whereby the following amounts of extracts dried at 100° were obtained

1 *Alcoholic Extract* 13.5% Dark yellowish green sticky mass smelling strongly of chlorophyll, also containing some crystalline mass. It gave a precipitate with lead acetate and silver nitrate, reduced Fehling's solution. Gave a green colouration with ferric chloride, no reaction with Meyer's reagent (for alkaloids)

2 *Petroleum Ether Extract* 10.3% A syrupy extract was obtained which contained nothing but chlorophyll

3 *Benzene Extract* 5.0% Properties similar to the above

4 *Acetone Extract* 9.4% A sticky mass consisting of chlorophyll and some crystalline matter was obtained. Properties similar to the alcoholic extract

5 *Aqueous Extract* 2.9% The extract was of a syrupy nature. It reduced Fehling's solution easily. Gave a bottle green colouration with neutral ferric chloride, a brown precipitate with Meyer's Reagent. Gave a negative test for glucosides

A preliminary examination was made with 200 gms. of the powdered drug. The alcoholic extract was treated with a little hydrochloric acid and tested for alkaloids with various reagents. The following precipitates or colourations were obtained —

Phospho-molybdic acid	A dark blue precipitate
Phospho-tungstic acid	A brown precipitate
Fröhdes' reagent	Do Do
Mandellin's reagent	. Brown colouration
Dragendroff's reagent	. Do Do
Meyer's reagent	.. Do Do



Picric acid	No change
Erdmann's reagent	A brown colouration
Sodium-bi-carbonate	No change.

In order to confirm the above result, another 200 gms of the finely powdered material were boiled with Prollius' solvent<sup>2</sup>, i.e., a mixture containing 88 parts ether, 4 parts ammonia (d 1.2) and 8 parts alcohol for two hours. The clear supernatant liquid was filtered off and sulphuric acid was added, the thick fluid was separated and treated with alkaloidal reagents with negative results.

In order to get a complete analysis 8 Kg. of the powdered drug was exhaustively extracted with boiling alcohol in a big extraction flask. The extract was filtered hot and concentrated to a small volume. A dirty brown crystalline mass separated on cooling which was greatly contaminated with chlorophyll. The mass then became dirty brown in appearance. This was crystallised from alcohol after refluxing with animal charcoal. Finally it was recrystallised from a mixture of acetone and alcohol, when brown microcrystalline flakes were obtained melting at 108-109°C (decomp). It was soluble in hot alcohol, hot acetone, chloroform, ether, and insoluble in water, petroleum ether, benzene, acetic acid, phenol and dilute mineral acids. It gave a darkish green precipitate with neutral ferric chloride, and a white precipitate with alcoholic lead acetate. It dissolved in alkalis and burned with a non-smoky flame (Found C, 64.61, 64.40, H, 9.49, 9.54, M.W. (decomposition of lead salt) 180, 184.  $C_{10}H_{18}O_3$  requires C, 64.5, H, 9.7% and M.W. 186).

It is proposed to call this acid *Burhaavio acid* in order to represent the generic name of the plant from which it is derived.

This acid was very inert since an attempt to prepare an acetyl derivative and an oxime proved unsuccessful. The only derivatives that could be prepared from it were the lead salt and a di-bromo-bromide.

**Lead Salt**—1 gm. of the acid was dissolved in hot alcohol and an alcoholic solution of lead acetate was added drop by drop when a flocculent white precipitate of the lead salt was obtained. This was filtered off, washed with alcohol and dried. It formed brownish white plates (Found Pb, 53.19, 53.4,  $C_{10}H_{17}O_3$ , Pb' requires, Pb, 53.0%).

**Di-bromo-burhaavio bromide**.—0.5 g of the acid was dissolved in chloroform and a solution of bromine in chloroform was added drop by drop till bromine was in slight excess. It was then warmed on a water-bath, and the excess of bromine removed by means of an aqueous solution of thiosulphate. On distilling back the chloroform, the bromo-derivative was obtained as a yellowish brown amorphous mass. This

was crystallised from alcohol, when it melted sharp at 73°C. In this reaction some elimination of hydro-bromic acid was also detected. (Found Bromine, 56.2%  $C_{10}H_{17}O_3Br_3$  requires Br, 56.4%)

The mother liquor after the separation of the above acid on standing deposited, white crystalline needles which were filtered and identified to be inorganic in nature. These on examination proved to be pure potassium nitrate, the presence of which in the plant greatly accounts for its medicinal value as a diuretic. Cf. Pendse and Dutt<sup>4</sup>, examination of *Solanum Xanthocarpum*.

The alcoholic mother liquor was then concentrated to a small bulk and dried in open for about a month. It smelt largely of chlorophyll and sugars. It was refluxed with benzene to remove chlorophyll till benzene became colourless. The stuff was then dissolved in hot alcohol and an alcoholic solution of lead acetate was added when a heavy yellow precipitate was obtained. This was filtered and washed. The filtrate on treatment with basic lead acetate gave another precipitate which was also filtered and washed. These precipitates were suspended in alcohol and water respectively and decomposed by hydrogen sulphide. The filtrates on the removal of the lead sulphide were evaporated, whereby amorphous dark brown hygroscopic products were obtained consisting mostly of tannins and phlobaphenes, since they gave a bottle green colouration with ferric chloride and dissolved in caustic soda being re-precipitated by acids. It also formed a red colouration with potassium ferricyanide and ammonia.

A portion of the filtrate after the removal of the lead salt, was freed from lead. It reduced Fehling's solution easily. In order to identify the sugar a portion was treated with acetic acid and phenyl hydrazine, when on warming an osazone was prepared (M.P. 203°C) showing the presence of glucose in the plant.

One of the authors (R. R. A.) wishes to express his indebtedness to the "Kanta Prasad Research Trust" of the Allahabad University for a scholarship, which enabled him to take part in the investigation.

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# SYNTHESIS OF SUBSTITUTED CINCHONINIC ACIDS THROUGH THE KNÖVENAGEL CATALYSTS

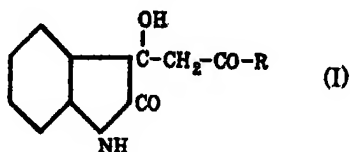
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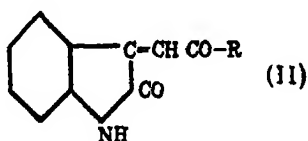
The Pfitzinger method<sup>1</sup> of synthesis of substituted cinchoninic acids like cinchophen from isatin and methyl ketones with strong potash as condensing agent affords a convenient method when no alkali sensitive groups are present. Recently Lindwall and MacLennan<sup>2</sup>, Braude and Lindwall<sup>3</sup> attempted to use the more gentle catalysts namely diethylamine, piperidine and ammonia suggested by Knövenagel<sup>4</sup> in place of the concentrated alkali. With these Knövenagel catalysts no substituted cinchoninic acids were obtained from an alcoholic solution of isatin and methyl ketone but compounds of the type (I) were formed



Thus with isatin and acetophenone no cinchophen was formed, but only 3-hydroxy-3-phenacyl oxindole, and isatin and acetone giving no 2-methyl-quinoline-4 acid but only 3-hydroxy-3-acetyl oxindole. Compounds of the type (I) decompose on heating near their melting points back into isatin and the methyl ketone. The same decompositions take place when products of the type (I) are warmed with potash solution for a short time. The product (I), therefore, is evidently only an addition compound and the decomposition an example of a reversed aldol-like condensation. When these compounds are, however, subjected to the drastic Pfitzinger conditions (heating it with strong alkali for a very long time) they yield the 2-substituted-quinoline-4-carboxylic acids. Lindwall and collaborators hold the view that this formation of the quinoline derivative from (I) did not occur through any molecular rearrangement

but rather through its decomposition back into isatin and the methyl ketone followed by condensation of the two according to the usual Pfitzinger mechanism

Treatment of compounds of the type (I) with dilute mineral acid resulted in its dehydration to yield the 3-substituted unsaturated oxindoles (II).



It might be expected that compounds of type (II) upon ring opening through hydrolysis would form the quinoline derivative as a result of subsequent reaction of the ketone carbonyl with the nuclear amino group. But this expectation could not be realised experimentally by those authors (*loc cit*) who suggest the possibility of compounds of the type (II) being *trans* isomers and their consequent failure to rearrange to give the quinoline derivatives. These results have led Lindwall and coworkers to suggest also that compounds of the type (I) and the 3-substituted unsaturated oxindoles (II) cannot possibly be intermediates in the Pfitzinger synthesis of substituted cinchoninic acids from isatin and methyl ketones. From this it is clear that Lindwall and collaborators could not obtain the substituted cinchoninic acids by the use of the Knoevenagel catalysts. These points have not yet been investigated completely. The present work was, therefore, undertaken to examine the conclusions of Lindwall and coworkers and see if it is possible to get substituted cinchoninic acids using the mild Knoevenagel catalysts instead of the drastic Pfitzinger one. The substituted cinchoninic acids are therapeutically important for their antineuralgic effects and as remedy for gout, and as an analgesic in the treatment of sciatica.

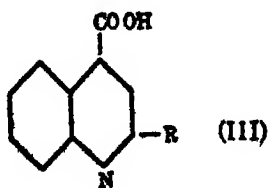
In cyclic compounds which are capable of giving rise to *cis-trans* isomerism it is well known that intramolecular reactions will take place more readily when the reacting groups are in the *cis* position to one another than when they are in the *trans* position and in certain cases it may be easy to produce in the *cis* compound a reaction which is difficult or impossible in the case of a *trans* isomer. This is exactly the position of the supposed intermediates (compounds of type (II)) in the Pfitzinger reaction. Lindwall and coworkers found that compounds of type (II) cannot rearrange to give substituted cinchoninic acids possibly because

they are *trans* isomers. It is very likely that the corresponding *cis* isomers would readily yield the desired products. This has actually been found to be the case. For effecting the geometrical inversion the method of Stoermer<sup>5</sup> was conveniently adopted. This consists in exposing the *trans* derivative in alcoholic solution to light rich in ultraviolet rays such as that furnished by the mercury vapour lamp. The *cis* modification thus obtained was found to give substituted cinchoninic acids on gentle warming with dilute potash. Thus it appears that geometrical inversion is necessary before (II) can rearrange to the corresponding cinchoninic acids. Since rearrangement is possible only in the *cis* form and since compound (II) after geometrical inversion yielded readily the desired product, *viz.*, the 2-substituted-quinoline-4 carboxylic acid it was reasonably presumed that compounds of type (II) are *trans* modifications and attempts at determining the actual configuration were dispensed with. Thus it is possible to get from isatin and methyl ketone the substituted cinchoninic acids, even by using the Knöevenagel catalysts. The synthesis may be expressed in the following stages.

The beta carbonyl of the isatin condenses with the methyl group of the methyl ketone giving the addition compound. (I)

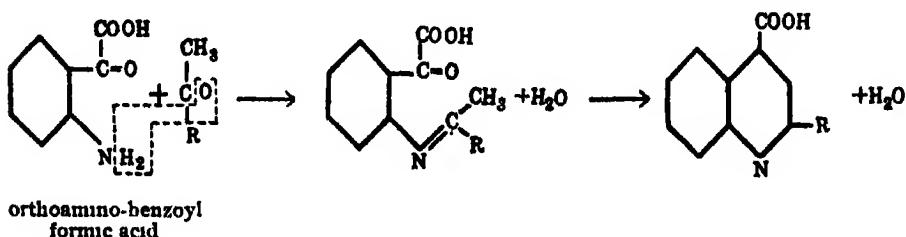
Beta-substituted isatins like isatin-beta anil, isatin-beta-bis-piperidyl, etc., give no products with these catalysts indicating that alpha carbonyl of the isatin does not take part in the condensation. N-methyl-isatin condenses with methyl ketones to give products similar in chemical properties showing that linkage of the methylketone to nitrogen of the isatin is an impossibility. Knöevenagel catalysts cannot compare themselves with the Pfitzinger condensing agent in these condensations, because isatin does not hydrolyse under these conditions but gives only the addition product (I) shown above. This product (I) is highly unstable and gives rise to (II) on treatment with dilute mineral acid by dehydration.

These unsaturated compounds are *trans* isomers and require geometrical inversion to give the *cis* compounds. These *cis* varieties on treatment with dilute-alkali and gentle warming gave (III) the 2-substituted cinchoninic acids.



It is therefore clear that the synthesis using Knœvenagel catalysts involves the use of several reagents in the different stages unlike in the Pfitzinger reaction where the formation of the cinchoninic acids is direct. This is usually conceived to take place as follows

The isatin hydrolysis into orthoamino-benzoyl-formic acid must be the first stage. Then the ketone carbonyl of the methyl ketone reacts with the amino group of the orthoamino benzoyl formic acid which must be the second stage. The alpha carbonyl of the isatin has been destroyed, of course, during the hydrolysis. In the third stage a molecule of water is eliminated from the carbonyl of the benzoyl-formic acid and of the methyl in the methyl ketone effecting thus a ring closure when the quinoline derivative is formed. This is usually accomplished at a single stretch, *viz.*, heating the reaction mixture from eight to ten hours



It was noticed that sun-light cannot bring about the geometrical inversion of the 3-substituted unsaturated oxindoles

### EXPERIMENTAL

- A (i) Condensation of isatin and acetone. 3-acetonyl-3-hydroxy oxindole (I). A mixture of 25 grs of isatin, 139 grs. of acetone and 139 grs of diethyl amine were allowed to stand overnight with a trace of ammonia (crystals were not obtained as reported by Lindwall and others). This was refluxed on a water bath for two hours. The hot liquid poured into ice-cold water when a solid mass was precipitated. Acetone was the best solvent for crystallisation; agreed in melting point and other properties with that obtained by Lindwall. (M P 166-167°C) yield 75%. Piperidine gave 60% and ammonia gave 73% yields.

- (ii) 3-acetonylidene-oxindole (II), compare Lindwall, (*loc. cit.*). Red needles from ethyl alcohol (M P. 168-171°C). Lindwall, M. P 169°C. 40% yield.

(iii) 2-methyl-quinoline-4-carboxylic acid (aniluvitonic acid) from isatin and acetone.

(a) Using Pfizinger method

25 grs of isatin, 139 grs of acetone, and 20 cc of 33% potash heated together for 9½ hours and acidified with dilute hydrochloric acid to precipitate a light brown substance. Boiling water was used to crystallise this which was later on identified to be 2-methyl-quinoline-4-acid

(b) Using Knœvenagel catalysts and subsequent geometrical inversion 5 grs of 3-acetylidenoxindole was dissolved in 45 cc of absolute alcohol and this solution placed in a cubical quartz cell. This was exposed to ultraviolet light from a mercury vapour lamp (with the proper condensing arrangements, etc.) for about 5 to 6 hours.

A crystalline solid gradually settled. This was separated and recrystallised from alcohol. It melted at 162°C. This was colourless and microcrystalline, on keeping it became slowly red (probably changing back into the more stable *trans* isomer). This powder was dissolved in 33% potash made just alcoholic and gently warmed in a water bath. On acidification with dilute hydrochloric acid a solid precipitated which was crystallised and identified to be 2-methyl-cinchoninic acid (yield 1.9 g) M P 242°C (compare Baeyer<sup>4</sup>). (Note.—Mulliken gives 240-241°C as one melting point and 246°C as another. Lindwall and coworkers do not mention the melting point of the product.)

(iv) Action of alkali on (I) A specimen of (I) on heating for 8 hours with sufficient excess of potassium hydroxide gave on acidification a precipitate which was identified to be 2-methyl-quinoline-4-acid

(v) Action of alkali on (II) A specimen of (II) on heating for 10 hrs. with potassium hydroxide in excess and acidification gave a dark tarry oil from which no substance could be purified

(vi) Action of sunlight on (II) A specimen of (II) on exposure to sunlight in (a) alkali solution (b) in alcoholic solution gave dark masses from which no substance could be purified.

B. (i) Condensation of isatin and acetophenone  
3-phenacyl-3-hydroxy-oxindole

Isatin 5 parts, acetophenone 4 parts, caustic potash (33%) 20 parts (Pfitzinger) or 10 parts of a basic catalyst (Knoevenagel) as diethyl amine, piperidine, ammonia, etc., were treated according to the procedure described by Lindwall (*loc. cit.*). Caustic potash gave the optimum yield of 80% (M P 169–172°C) with decomposition

(ii) 3-phenacylidene oxindole (compare Lindwall and others) M. P 193–194°C

(iii) cinchophen (2-phenyl-quinoline-4-carboxylic acid) from isatin and acetophenone

(a) Using Pfitzinger method Compare method A (iii) (a) Needles melting at 210°C

NOTE — (Pfitzinger gives its melting point as 208–209°C (*loc. cit.*) Boehm and Bournot<sup>7</sup> report it to be 212–213°C Lindwall and others do not record their melting point in their paper but only say that they identified it by mixed melting point)

(b) Using Knoevenagel catalysts and subsequent geometrical inversion (of 2-phenacylidene oxindole)

Compare A (iii) (b)

(The *cis* modification melted at 193°C yield 3 g from 5 g. of (II). It was microcrystalline.)

(iv) Compare A (iv) melting point of product 210°C.

(v) Compare A (v) above

(vi) Compare A (vi) above

A few more substituted cinchoninic acids are being studied from this point of view My sincere thanks are due to Mr. G Gopala Rao, M Sc, A I.C, for the kind interest he has taken in my work.

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# PHOTOSYNTHESIS OF FORMALDEHYDE FROM 'NASCENT CARBON DIOXIDE' *IN VITRO* AND THE IMPORTANCE OF RESPIRATION IN PHOTOSYNTHESIS

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In several publications<sup>1</sup>, from these laboratories we have shown that formaldehyde can be actually obtained from the photochemical reduction of carbon dioxide in aqueous solutions in the presence of various inorganic and organic photocatalysts. In the absence of a photocatalyst, the yield of formaldehyde obtained in these experiments, is very small. Further, it has been shown that dilute solutions of alkali bicarbonates when exposed to sunlight, yield small amounts of formaldehyde even in the absence of a photocatalyst. Recently<sup>2</sup>, we have been able to obtain greater yields of formaldehyde by exposing to sunlight bicarbonate solutions in the presence of metals like magnesium, iron, cerium, etc., and that the reaction is accelerated by light.

In all these experiments carbon dioxide which has been used is in the inactive state. The reaction



is a highly endothermal one and requires a wavelength of about 2550 Å. The fact that bicarbonate solutions yield formaldehyde on exposure to sunlight even in the absence of photocatalysts, clearly points out that there is some difference in ordinary carbon dioxide and that produced in the photodecomposition of bicarbonates. The only difference that seems to exist between these two varieties of carbon dioxide is that carbon dioxide obtained from the decomposition of bicarbonates is in the nascent state. If that is so, then nascent carbon dioxide should yield formaldehyde more readily than the ordinary variety without using any photocatalyst, whenever it can be produced in

the presence of sunlight. This has already been confirmed by the author<sup>3</sup> It has been shown that formaldehyde can be easily obtained from nascent carbon dioxide prepared by the interaction of carbonates of barium, calcium, strontium and sodium with hydrochloric acid, when the whole system is exposed to light in the absence of any coloured substance.

Thus it seems pretty certain that nascent carbon dioxide can be photochemically reduced to formaldehyde more readily than ordinary carbon dioxide. In all these experiments nascent carbon dioxide has been generated from inorganic materials. Is there a possibility of generating carbon dioxide in a nascent state from organic substances and utilising it for the photosynthesis of formaldehyde? A serious attempt has been made along this line and in the following pages I shall try to give an account of the experiments that have been carried on to test this point.

It is well known that many organic compounds yield formaldehyde on exposure to sunlight and air. The action of light on organic substances has been studied by many observers. The important work on this subject is that of Usher and Priestley<sup>4</sup>, Jørgensen and Kidd<sup>5</sup>, Warner<sup>6</sup>. These authors have made an extensive investigation on the generation of formaldehyde when films of chlorophyll are exposed to sunlight in the presence and absence of air. The origin of formaldehyde detected when aqueous solutions or suspensions of organic substances are exposed to sunlight and air, has not yet been satisfactorily explained.

With a view to the elucidation of the mechanism of generation of formaldehyde from the photodecomposition of organic substances and also to see whether there is any relation between the production of formaldehyde from organic substances and photosynthesis by the plants a systematic investigation on the formation of formaldehyde by exposing solutions or suspensions of various organic substances to sunlight and air has been undertaken.

### EXPERIMENTAL

Dilute solutions of the organic substances were exposed in open beakers to sunlight for about six hours, and after the desired exposure the solutions were distilled and the amount of formaldehyde estimated by the iodine method or colorimetrically by the Schryver's reagent using the Dubosq type of colorimeter. As a result of the estimation of the amount of formaldehyde obtained from the photodecomposition of organic substances they have been divided into the following three groups.

Table I

## GROUP A

*The amount of formaldehyde obtained from 100 cc of the solution exposed, varying from 0.0007 to 0.0015 g*

Experiment	Time of exposure in hours.	Amount of formaldehyde in grms per 100 cc of the solution exposed
1 50 cc dilute acetic acid containing 5 cc glacial acetic acid .	6 hours.	0.0015
2 50 cc of 1% solution of glycine	do	0.0016
3 50 cc of 0.02% solution of methyl violet ...	do.	0.0012
4 50 cc of 0.02% solution of malachite green	do.	0.001
5. 50 cc of 0.02% solution of victoria blue .	do	0.001
6 50 cc of 0.02 solution of methylene blue ...	do	0.0008
7 50 cc of 3% solution of citric acid ...	do.	0.001
8 50 cc of 5% solution of lactic acid ...	do	0.001
9 50 cc of a solution of guaiacol (absolute) containing 1 cc.	do	0.0009
10 50 cc of water containing 0.05 gr of pure chlorophyll ..	do.	0.0007
11 50 cc. of 5% solution of monochloroacetic acid ..	do.	0.0015

Table II

## GROUP B

*The amount of formaldehyde obtained from 100 cc. of the solution exposed, varying from 0.0001 to 0.0006 g*

Experiment.	Time of exposure.	Amount of formaldehyde in grms obtained from 100 cc of the solution exposed.
1 50 cc of a dilute solution of pyruvic acid . ...	6 hours	0.0004 g
2. 50 cc of 2% tartaric acid	do	0.0002 g
3. 50 cc of 0.02% phloxine	do	0.0001 g.
4 50 cc of 0.02% aurine ...	do.	0.00016 g
5 50 cc 0.02% solution of gallo-mine blue	do	0.0003 g
6. 50 cc of 0.02% solution of 4,5 dihydroxy fluran ...	do	0.0003 g.
7. 50 cc of 1% solution of levulose ...	do	0.0006 g
8 50 cc. of 5% solution of galactose .. ..	do	0.0003 g
9 50 cc. of 5% solution of butyric acid ... ..	do	0.00012 g.
10 50 cc of 5% solution of propionic acid	do.	0.00012 g

Table III

## GROUP C

*The amount of formaldehyde obtained from 100 cc of the solution  
varying from 0.000015 to 0.0001 g*

Experiment	Time of exposure in hours.	Amount of formaldehyde in grams obtained from 100 cc of the solution exposed.
1 50 cc. of a solution of sodium oleate, M/100	6 hours	0.0001
2. 50 cc sodium butyrate solution M/100 ..	do	0.00015
3 50 cc. of a 0.02% solution of congo red .	do	0.00003
4 50 cc. of a 0.02% solution of safranine	do	0.00003
5. 50 cc of 0.02% solution of oxalic acid .	do	0.00004
6 50 cc. of a solution of starch 1% ... ..	do	0.00003
7. 50 cc of a solution of inulin, 1% ... ..	do.	0.00003
8 50 cc. of a solution of glucose, 1% ... ..	do	0.00005
9. 50 cc of a solution of cane sugar, 1%	do	0.00004
10 50 cc of a 0.02% solution of acridine yellow ...	do.	0.00006
11. 50 cc. of a 0.02% solution of orthochrome ...	do.	0.00007
12 50 cc. of 3% solution of gelatine ... ..	do.	0.00006

Experiment	Time of exposure in hours	Amount of formaldehyde in grams obtained from 100 cc of the solution exposed
13. 50 cc of 1% solution of glutamic acid	6 hours	0 00004
14. 50 cc of a 1% solution of arginine	do	0 00008
15. 50 cc of a 0 02% solution of pinacyanole	do	0 00005
16. 50 cc. of a 0 02% solution of benzopurpurin	do	0 00004
17. 50 cc of 0 02% solution of pinachrome ...	do.	0 00005
18. 50 cc. of a solution of alanine, 1% .	do	0 00004
19. 50 cc of a 1% solution of histidine ...	do	0 00005
20. 50 cc of 1% solution of asparatic acid ...	do	0 000055

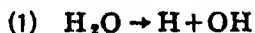
### Discussion

It has already been pointed out that aqueous solutions of bicarbonates of alkali metals give formaldehyde on exposure to sunlight. It is well known that bicarbonate solutions decompose into the corresponding carbonate and carbon dioxide. Thus carbon dioxide which is generated in the decomposition of bicarbonates is in the nascent state and hence is energy rich. The extra amount of energy which it possesses by virtue of being a nascent molecule may be partly utilised for its activation in order to be reduced to formaldehyde. To obtain formaldehyde from bicarbonate solutions it is not necessary to add any photosensitiser as with ordinary carbon dioxide. Thus it is clear that nascent carbon dioxide is more readily reduced to formaldehyde than ordinary carbon dioxide and the reason of this peculiar behaviour

is to be ascribed to the extra amount of energy possessed by the former. That formaldehyde is also obtained from carbon dioxide generated by the interaction of colourless carbonates like those of barium, calcium, etc., and mineral acids without the addition of any photosensitiser also supports the view that nascent carbon dioxide is more capable of yielding formaldehyde on its photochemical reduction than the ordinary one, simply because in these experiments too, nascent carbon dioxide is responsible for the production of formaldehyde.

What is the origin of formaldehyde produced from the photodecomposition of photo-oxidation of organic compounds? From the list of substances given in tables I, II & III it will be seen that they belong to different classes of organic compounds and hence no general rule as to the production of formaldehyde from these substances can be formulated. The organic compounds mentioned above have been classified into three groups according to the amount of formaldehyde obtained in their photodecomposition or photo-oxidation and not with respect to their chemical nature.

In the first group, the substances on exposure to light and air yield formaldehyde very readily and in sufficient amounts. By carrying on experiments in the dark and in the absence of air we have observed that no formaldehyde is formed in the dark or in the absence of air. When solutions of these substances are exposed to light and air, formaldehyde is formed mainly as a direct product of photo-oxidation. In a recent communication<sup>7</sup>, it has been advanced by the author that the first stage in photosynthesis by the plants and *in vitro* is the photolysis of water molecules into H and OH. Thus in the case of glycine the following change may take place in the presence of air and light.

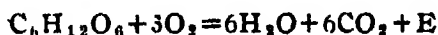


and in the case of acetic acid;



This mechanism can very easily explain the production of formaldehyde from acetic acid, by the oxidation of methyl alcohol. The production of formaldehyde from the second class of substances may not be entirely due to the direct photo-oxidation of the substance, but due to the joint action of oxidation and photosynthesis (explained later).

*Mechanism of the production of formaldehyde from substances of the third group and the Formaldehyde Theory of Carbon Assimilation.*—It is well known that carbon dioxide and water are always generated whenever an organic compound is slowly oxidised, and an appreciable amount of energy is simultaneously set free. For instance, in the case of glucose,



The carbon dioxide so produced, at the moment of its generation will be in the nascent state or energy rich, since it is being produced in the presence of a large amount of energy. The reaction,



is a highly endothermal one, and very difficult to be brought about in the usual way. From the thermodynamic considerations the above reaction demands a minimum frequency of  $1.75 \times 10^5$  e., a wavelength of  $2552 \text{ \AA}$ . Thus it is clear that without the help of an efficient photocatalyst, it is difficult to obtain formaldehyde from the photochemical reduction of carbonic acid. But all these experiments have been carried on in the absence of any photosensitiser, hence a mode of activation of ordinary carbon dioxide should be sought for, in order to explain photosynthesis of formaldehyde from carbonic acid.

The greater efficiency of nascent carbon dioxide which is energy rich, must be attributed to the higher energy content (which it possesses as a freshly generated molecule), than one of ordinary carbon dioxide. Thus a molecule which is already endowed with energy, should require less energy for its activation than one which is deficient in it and hence nascent carbon dioxide can be photochemically reduced to formaldehyde more readily than ordinary carbon dioxide. Since nascent carbon dioxide and water are being produced from organic substance in the presence of sunlight and it is very likely that under the action of sun's rays they should combine even in the absence of any photosensitiser. It is this formaldehyde which is being detected in the photo-oxidation of organic substance.

From these considerations it appears that the source of formaldehyde generated in the photo-oxidation of substances like oxalic acid, acridine yellow, alanine, cane sugar, etc., is not the direct photo-oxidation of the latter, but its photosynthesis from the nascent carbon dioxide and water generated during photo-oxidation of the organic substances. It is due to this reason that formaldehyde is detected in the photo-oxidation of



organic substances because the two ingredients are almost universally generated during the oxidation of the former. From comparative experiments it has been found that a solution of alanine is decomposed to a greater extent than a solution of glycine of the same concentration, though the amount of formaldehyde formed from the latter is at least twenty times as much as from alanine. This is simply due to the reason that in the case of glycine, formaldehyde is obtained as a direct product of photo-oxidation of the former whilst with alanine it is obtained photosynthetically from energy rich carbon dioxide generated in the oxidation.

In this connection it will be worthwhile noting that formaldehyde is obtained even in the dark by treating carbonic acid or bicarbonate solutions with metals like magnesium, cerium, iron, etc. Recently we have been able to show that small amounts of formaldehyde are obtained by treating bicarbonate solutions with yellow phosphorus. In these cases the amount of formaldehyde formed is greater in light than in the dark. It appears that the energy rich hydrogen produced by the action of metals on water is capable of reducing the bicarbonate ion or carbonic acid to formaldehyde even in the dark, aided by the energy produced by the reaction of the metal on carbonic acid and bicarbonate solutions.

From the results of quantitative experiments carried on in this connection it has been found that the ratio of the mol of the substance decomposed to the mols of  $\text{HCHO}$  formed is approximately unity in the case of substances of the first group (acetic acid and glycine), whilst with the substances of the third group this value has been found to vary from 35 to 300. These results afford another argument in favour of the view advanced here, because the efficiency of the photosynthetic process is very low and hence all the molecules of carbon dioxide in the photo-oxidation cannot take part in the reaction, that is why in this case the ratio comes out to be very high.

From this theory it is expected that the yield of formaldehyde should be greater, the greater the energy generated in the oxidation of the organic substance. It has been experimentally found that the fats give more formaldehyde on their photo-oxidation than carbohydrates or the proteins, though the fats are oxidised less than the other two classes of substances. This is due to the fact that fats give out more energy on their oxidation than the carbohydrates or the proteins, and thus causing the reduction of carbonic acid to a greater extent.

The production of formaldehyde in the oxidation of organic substances has been regarded by several authors as an argument against the formaldehyde theory of photosynthesis, but from the views advanced here it will be seen that this fact instead of being against the theory lends appreciable support to this view

*Importance of Respiration in Photosynthesis.*—It seems very likely that the energy generated in the photo-oxidation of organic compounds supplies a part of the energy required for the photosynthesis of formaldehyde from carbon-dioxide obtained from the oxidation of organic substances and that is why formaldehyde can be more readily detected in the photo-oxidation of organic compounds which liberate energy in their oxidation, than in the case where ordinary carbon dioxide or bicarbonate solution are exposed to sunlight. Many plant physiologists have tried to connect respiration with photosynthesis, but the mechanism in which these two fundamental processes going on in the plants may be related is not yet clearly understood. Thus, Spoehr (*Photosynthesis*, 1926, p. 143) states, "Also, the light green varieties have lower rate of respiration than the normal plants, though there is no direct parallelism between respiration and chlorophyll content. A closer relationship seems to exist between the rate of photosynthesis and that of respiration." A relation between respiration and photosynthesis has been observed by Miss Henrić also (Inaug. Diss., Basel 1918). She has observed in the study of alpine and lowland plants that those plants which had a high photosynthetic rate also have a high rate of respiration and *vice versa*.

In previous pages it has been shown that the greater the energy evolved in the oxidation of the substance the greater is the amount of formaldehyde formed. Instead of the oxidation of an organic substance which is the source of energy here, any other suitable exothermal reaction will suffice to increase the yield of formaldehyde from the photo-oxidation of organic substance. Since respiration is the oxidation of carbohydrates and other food materials of the plant, it follows from the viewpoints advanced here, that the greater the rate of respiration, the greater is the possibility of a supply of energy for photosynthetic purposes. Thus respiration is directly related to photosynthesis and the way in which it is related to the latter, is the supply of a part of energy (evolved during respiration) which is required for photosynthesis.

Just as photosynthesis *in vitro*, i.e., the formation of formaldehyde by exposing solutions of carbonic acid to sunlight, is exceedingly difficult in the absence of an exothermal reaction taking place along with

it, carbon assimilation in plants is also practically impossible in the absence of a supply of energy available from respiration. It will be interesting to note here that the formation of urea in the body is greatly enhanced by respiration. It appears, therefore, that besides light, carbon dioxide, moisture and chlorophyll, energy from respiration is also necessary for photosynthesis, and that is why those plants which respire well also photosynthesise well.

The author is carrying on these experiments further and a comprehensive theory of photosynthesis based on these observations will be given in a subsequent paper. My best thanks are due to Professor N. R. Dhar, for the keen interest that he has taken during the progress of this work.

#### SUMMARY

1. When solutions of organic substances like acetic acid, citric acid, glycine, malic acid, lactic acid, glycogen, acetone, etc., are exposed to sunlight and air, formaldehyde is readily detected.

2. It has been shown that the aqueous solutions of the dyes like malachite green, methylene violet, methylene blue, etc., form formaldehyde readily on photo-oxidation. These dyes also behave as antiseptics, and it is very likely that the production of formaldehyde from these substances when exposed to light, may be the real cause of the antiseptic action.

3. Tartaric acid, butyric acid, propionic acid, and some other dyes form smaller quantities of formaldehyde while oxalic acid, formic acid, glucose, cane sugar, starch, histidine, etc., produce very small amounts of formaldehyde from photo-oxidation.

4. It is believed that formaldehyde formed in the first group of substances is a direct product of the photo-oxidation, whilst with oxalic acid, starch, glucose, etc., formaldehyde is obtained from the photosynthesis of energy rich carbon dioxide and water produced during photo-oxidation.

5. It seems probable that the energy generated in the photooxidation of organic compounds supplies a part of the energy required for the photo-formation of formaldehyde. In nature, photosynthesis that takes place in plants is aided by the energy obtained in plant respiration.

6. In the plant kingdom, the process of respiration and photosynthesis seem to be very intimately connected, because photosynthesis cannot proceed without the energy available from respiration for the partial activation of carbon dioxide and water vapour.

7 Formaldehyde can be obtained in a much easier way from carbonic acid or bicarbonate solutions on exposure to sunlight when a suitable exothermal reaction is taking place in the system along with the photosynthetic reaction

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# ON AMPHISTOME PARASITES OF SHEEP AND GOAT FROM ALLAHABAD

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## Introduction

The table given below gives in brief the analysis of most of the contributors of the Amphistomata Group in the last thirty years

TAB E I

No	Host	Subfamilies	Contributors
1	Fishes	<i>Diplodiscinae</i> <i>Schizamphistominae</i> <i>Cladorchinae</i>	Fishes Daday, 1901, Nicoll, 1915, Goto and Mutsudaira, 1918 Travassos Artigas, and Pereira, 1928, Vaz, 1932 Amphibia Cohn 1904, Johnston, 1912, Stunkard, 1917, Mac Callum, 1917 Reptiles Cohn 1904, Looss, 1912; Stunkard, 1917
2	Amphibia		
3	Reptiles		
4	Birds	<i>Zygocotylinae</i>	Fischoeder, Stunkard, 1917.
5	Mammals	<i>Paramphistominae</i> <i>Gastrodiscinae</i> <i>Balanorchinae</i> <i>Pfenderinae</i>	Fischoeder, 1901-03, Leiper, 1908-10, Stiles and Gold- berger, 1910, Mac Callum, 1917; Maplestone, 1923, Fukui, 1926-1929

The contributions to this group in the 19th century have been those of Rudolphi, 1809, Diesing, 1835; Creplin, 1839-47, Sonsino, 1876-95, Poirier, 1882-83; Monticelli 1888 In the last thirty years the most important contributions to this group have been those of Fischoeder, 1901-03, Cohn, 1904, Leiper, 1908-10, Stiles and Goldberger, 1910; Odhner, 1911; Looss, 1912; Johnston 1912, Stunkard, 1917; Maplestone, 1923; Fukui, 1926-29, Travassos, Artigas and Pereira, 1928 and Vaz, 1932. But we owe

our present knowledge of the classification of the group to the efforts of Monticelli, 1888, Braun, 1889-93, Fiscoeder, 1901-03, Stiles and Goldberger, 1910, Stunkard, 1917 and 1925, Maplestone, 1923 and Fukui, 1929

In 1892 Monticelli for the first time divided the family *Paramphistomidae* into two subfamilies *Gastrodiscinae* for *Gastrodiscus* and *Cladorchinae* for the remaining amphistomes

Fiscoeder (1901) further divided the subfamily *Cladorchinae* and created one more subfamily *Paramphistominae* to include the amphistomes of mammals, characterised by the presence of lobed testes, absence of paired oral evagination and cirrus sac, whereas the *Cladorchinae* distinguished from it by the presence of branched testes, paired oral evaginations and cirrus sac. He dropped the subfamily *Gastrodiscinae* and included the genus in the *Cladorchinae*. Cohn (1904) created the subfamily *Diplodiscinae* for *Diplodiscus*, *Opisthodiscus*, and *Catadiscus*, found in amphibian and reptilian hosts. In 1910 Stiles and Goldberger while proposing a new system of classification created a new superfamily *Paramphistomoridea* to include the forms hitherto classed as amphistomes and divided it into three families *Paramphistomidae*, *Gastrodiscidae* for *Gastrodiscus* Luck and *Homalogaster* Poir. and *Gastrothylacidae* for the four genera *Gastrothylax*, *Wellmannius*, *Curmyerius* and *Fiscoederius*, the last three being created by them. This classification, however, received criticism by Braun (1911), Odhner (1912), Looss (1912). Stunkard (1917) also remarked, "The classification of Stiles and Goldberger as pointed out by other authors is based on superficial characters and the elevation in rank of the family is in most cases unwarranted. However, the subfamily *Gastrodiscinae* of these authors, appears to be clearly distinguished by the presence of the large ventral pouch and in my opinion should be retained." Fukui, however, denied the importance of the ventral pouch as a family or subfamily character. In his opinion the structure of the oral sucker and the topography of the genital organs bring the genus *Gastrothylax* close to *Paramphistoma* in the subfamily *Paramphistominae*. Maplestone (1923) adhering to *Amphistoma* Rudolphi (1801) *et passim*, Nitsch (1819) recognised the super family *Paramphistomoridea* and the three families *Gastrothylacidae*, *Paramphistomidae*, and *Gastrodiscidae*. This has been criticised by Stunkard and Fukui in 1925 and 1929 respectively. Fukui who has given a complete historical review of the classification, has divided the subfamily *Paramphistominae* into three tribes *Paramphistomineae* (without oral evagination), *Stephanopharyngineae* (with a single oral evagination) and *Pseudodiscineae* (with paired oral evagination). In my opinion the presence or absence of single or paired oral evaginations as

an important character distinguishing the various genera renders the creation of tribes within the *Paramphistominae* unnecessary

Stiles and Goldberger (1910) divided *Gastrothylax* Poir into four genera *Gastrothylax*, *Fischoederius*, *Curmyerius* and *Wellmannius* of which the last two were held synonymous by Maplestone (1923) with which Fukui agrees with this difference that the latter author reduces them to the rank of subgenera. My study of the two species *G. crumenifer* and *G. elongatus* collected from the sheep and goat of Allahabad, India, lead me to think that the genus *Gastrothylax* Poir should be retained and that the other two genera or subgenera, *i.e.*, *Fischoederius* and *Curmyerius* should be merged into it as the excretory and lymphatic systems of *G. crumenifer* and *G. elongatus*, which are included different subgenera, resemble closely. For similar reasons Fukui reduced the genus *Cotylophoron* Stiles and Goldberger (1910) to the rank of a subgenus and included it with three new subgenera *Buxifrons*, *Paramphistoma*, and *Explanatum* in the genus *Paramphistoma* Fischoeder (1901). The creation of the above-mentioned subgenera of *Paramphistoma* on the basis of the position of testes only, I think, unnecessary. I therefore retain the genus *Cotylophoron* as created by Stiles and Goldberger, (1910).

A large number of stomachs of the "Desi" variety of sheep and goat at Allahabad yielded during the years 1931-33 in the months of July to September amphistomatous parasites of the genera *Gastrothylax* and *Cotylophoron*, the list of which as arranged genera-wise is given in Table 2

TABLE 2

Genus	Host	Rate of infection	Location
1. <i>Gastrothylax</i>			
<i>G. elongatus</i>	Sheep	80 per cent	Stomach
<i>G. crumenifer</i>	Goat	80 per cent	Stomach
2. <i>Cotylophoron</i>			
<i>C. oratum</i> n. sp.	Sheep and Goat	100 per cent	Stomach
<i>C. orientalis</i> n. sp.	Sheep and Goat	100 per cent	Stomach
<i>C. elongatum</i> n. sp.	Goat	60 per cent	Stomach

The present paper contains a report on the occurrence of parasites belonging to the genus *Gastrothylax* Poirier 1883 and the description of three new species of the genus *Cotylophoron* Stiles and Goldberger (1910). For the sake of convenience only one species of *Cotylophoron* is described in detail and only diagnostic characters of the two species are given, whereas the excretory and lymphatic systems of all of them are, however, described at some length.

I am much indebted to Dr H R Mehra for his valuable help and for making necessary corrections in the manuscript.

### Report on the occurrence of the species of the genus *Gastrothylax*

Hitherto no study of the genus *Gastrothylax* has been reported from Sheep and Goat of India or any other part of the world. Maplestone, however, reported the occurrence of *G. crumenifer* in the Indian bullocks, while several other workers have recorded the occurrence of the various species of this genus from the cattle other than Sheep and Goat in different parts of the world. Both Sheep and Goats are found heavily infected at the same time with one species of *Gastrothylax* along with one or two species of *Cotylophoron*. In some goats, however, all the species of *Cotylophoron* are met with along with a species of *Gastrothylax*. The number of these parasites usually varies from hundred to two hundred, in two cases the number varied from fifteen to twentyfive only. It is interesting to point out that the species of *Gastrothylax* from goat agreed in all anatomical details with *G. crumenifer* Creplin (1847), Poirier (1883), and that from sheep with *G. elongatus* Poirier. The excretory and lymphatic systems conform almost to the same plan as given by Fukui (1929).

### Key to species of *Gastrothylax* Poirier (1883)

- |   |  |                       |
|---|--|-----------------------|
| 1 | Cephalic half of uterus and vas deferens separated on opposite sides | <i>G. crumenifer</i>  |
|   | Cephalic half of uterus and vas deferens both median                 | 2                     |
| 2 | Testes side by side, lobed   | 3                     |
|   | Testes obliquely dorsoventral, lobed                                 | 4                     |
| 3 | Genital aperture anterior to the aperture of the ventral pouch       | .. <i>G. exoporus</i> |
|   | Genital aperture concealed in the pouch                              | 5                     |
| 4 | Caeca short, ending at about middle of body                          | <i>G. elongatus</i>   |
|   | Caeca long, reaching acetabulum                                      | <i>G. eobboldi</i>    |



5. Excretory pore and pore of Laurer's canal common, *G. irenyoni*  
Excretory pore and pore of Laurer's canal separate, 6
6. Caeca reaching acetabulum *G. spithosus*  
Caeca not reaching acetabulum .. *G. gragarius*

### Generic diagnosis of *Cotylophoron*.

*Paramphistominae* Oesophagus with or without muscular thickening, caeca long wavy, ending in acetabular zone Acetabulum of moderate size, terminal, tilts ventrad Excretory pore pre or post-vesicular Genital sucker near or behind intestinal bifurcation Genital papillae present Testes smooth or lobed, tandem or oblique Ovary median or submedian, post-testicular Laurer's canal may or may not cross the excretory canal Vitellaria lateral or spreading throughout the body Excretory system simple with a canal on each side or simple H-shaped or H-shaped with two canals on each side Lymphatic system simple or branched

Type species — *Cotylophoron cotylophorum* Fischöeder (1901).

### *Cotylophoron ovatum*, n sp

During the period from July to September an equal percentage of sheep and goat harboured this species in an enormous number The worms, in living condition, while attached to the stomach villi, are white with a reddish-brown patch in the middle showing no movement of contraction or expansion, but when placed in salt solution they show antero-posterior movements of contraction and expansion keeping alive for more than sixty hours

The body is dorsoventrally thick and oval in outline, measuring 4.32—6.63 mm in length and 2.20—2.30 mm in its maximum breadth which lies in the middle of the body length The body wall is devoid of spines; but in the anterior half from the cephalad end to the level of the intestinal bifurcation it is thrown into small protuberances or papillae which are broad at the base and bluntly pointed at the end

The terminal oral sucker, 0.38—0.61 mm in length and 0.326—0.442 mm in its maximum breadth, has its lumen narrow dorsoventrally but much broad transversely. The papillae, present internally in the oral sucker of *G. indium* are absent in this species. The oesophagus with thick muscular walls measures 0.368—0.53 mm in length and 0.88—1.16 mm in its maximum breadth near the intestinal bifurcation The limbs of the intestinal fork are almost at right angles to the oesophagus The

intestinal diverticula which are comparatively thick have an almost zigzag course extending up to the cephalad margin of the acetabulum or a little behind it. Posteriorly situated acetabulum, 0.526–0.90 mm in diameter, is completely tilted ventrad.

The main reproductive organs are situated in the posterior two-thirds of the body. The testes of almost equal size are rounded and lie close behind each other. Their zones do not overlap as in *C. indicum*. The anterior testis measures 0.884–1.159 mm in length and 1.05–1.41 mm in breadth and the posterior testis, 0.84–1.284 mm in length and 1.00–1.39 mm in breadth. The vasa efferentia arise from about the middle of the anterior margin of the testes and unite a little anterior to cephalic testis in the median line to form the vas deferens which enters the transversely coiled thin walled vesicula seminalis. The latter passes into the highly muscular and transversely coiled pars muscosa. The pars prostatica, 0.90 mm in length, is well developed and is almost obliquely situated in the ventral half of the body. The short ductus ejaculatorius unites with the metraterm to form the ductus hermaphroditicus which traverses the centre of the genital sucker between the genital papillae to open to the exterior. The genital sucker, 0.24–0.32 mm in diameter, lies 0.16 mm. behind the intestinal bifurcation. The genital pore is of *Paramphistome cervi* type as mentioned by Fukui.

The ovary and shell glands lie in the post-testicular zone between the caudal testis and the dome of the acetabulum. The ovary with an entire outline is situated slightly to the right side, slightly broader than long, measuring 0.22–0.42 mm in length and 0.33–0.42 mm in breadth. The shell gland mass is almost median and situated just behind the ovary. The uterus, which extends from the ventral pole of the shell gland mass to the genital sucker, runs transversely towards the left intestinal caecum and then passes forwards inside the latter till it reaches in region between the two testes, where it forms two or three transversely arranged coils on the dorsal side, to continue its forward course to enter the metraterm. The eggs measure 0.13–0.132 mm in length and 0.069 mm in breadth.

The vitellaria are highly developed, composed of closely set or scattered follicles of 0.30–0.71 mm length and 0.32 mm breadth, and almost extracaecal extending from about the intestinal fork to the middle of the acetabulum; sometimes they overlap the caeca almost completely both on dorsal and ventral sides and may even enter the intracaecal area. The vitelline ducts run longitudinally converging centrad at about the middle of the posterior testis, the right one

situated outside the ovary and the shell gland mass, and unite ventrally just behind the latter close in front of the acetabulum

The Laurer's canal is slightly coiled and opens dorsally in the median line a little anterior to the excretory opening

The excretory system is simple. The excretory bladder is rounded and situated submedian between the shell gland mass and the anterior margin of the acetabulum, sometimes entering a little behind the latter. The collecting ducts run one on each side, between the intestinal caeca and the body wall almost parallel to the latter from about the caudal margin of caeca to the level of the middle of the oral sucker

The lymphatic system is also simple conforming almost the same configuration as that of the excretory collecting ducts

Host—Sheep and Goat

Habitat—Stomach

Locality—Allahabad (India)

### ***Cotylophoron orientalis* n sp**

Body elongated, bluntly pointed at cephalic and rounded at posterior ends, 7.56–9.35 mm in length and 2.98–3.16 mm in its maximum breadth. Cutical smooth and devoid of protuberances or papillae as present in *C. ovalum* n sp. Terminal oral sucker 0.68–0.935 mm in diameter. Oesophagus highly muscular 0.54–0.73 mm in length with uniform width of 0.17–0.25 mm. Intestinal bifurcation, acute angled situated 0.68–0.85 mm anterior to the genital sucker of 0.25–0.34 mm diameter

Testes irregularly lobed, oblique, separated from each other by a short distance, intracaecal, situated in the third quarter of body length, anterior testis 0.59–1.39 mm in length and 0.71–1.31 mm in breadth, posterior testis 0.81–1.36 mm in length and 1.60 mm in breadth. Vasa efferentia arise from outer margins of the testes on opposite sides and unite a little anterior to the anterior testis. Coiled vas deferens shorter than pars muscosa; pars prostatica highly developed

Ovary, median or submedian (0.255–0.48 by 0.34–0.51 mm) slightly broader than long and situated in first half distance between posterior margin of caudal testis and acetabulum. Shell gland mass is median a little behind ovary. Laurer's canal present. Uterus much coiled behind ovary, less coiled in front running irregularly in median line. Vitellaria of moderate size, 1 ♂, less highly developed than in *C. ovalum* n sp. extending from about oesophagus to about one-third of acetabulum and coalescing

in the region of genital sucker and post-ovarian zone. Ova 0.136 by 0.085 mm

Excretory vesicle, median and transversely oval with a short wide transverse canal originating from it on each side which divides into three branches of almost equal caliber, one short running posteriorly and other two long running forwards on each side. Outer one of the anterior branches runs cephalad in an annular manner along with intestinal caecum of that side, inner one runs cephalad almost parallel to body wall as far as a little distance in front of genital sucker, where it unites in an arc with that of the other side. More than six branches are given off anteriorly from the arc of which outermost runs obliquely.

Two lymphatic ducts present on each side of which outer one runs in an annular manner along with intestinal caecum of that side and inner one runs almost parallel to body wall.

Host—Sheep and Goat

Habitat—Stomach

Locality—Allahabad (India)

### ***Cotylophoron elongatum* n. sp.**

Body elongated 11.58–15.30 mm. long and 2.93–4.65 mm wide in acetabular zone. Cuticle smooth and devoid of papillae. Oral sucker terminal, 0.75–0.935 mm in diameter. Oesophagus muscular, 0.76–1.07 mm. long. Intestinal bifurcation acute-angled about 1.36 mm anterior to genital sucker of 0.34–0.59 mm diameter. Intestinal caeca zigzag up to posteriorly situated acetabulum of 1.97–2.38 mm diameter.

Testes lobed, tandem, broader than long, of almost equal size (1.68–2.04 by 1.78–2.12 mm) situated in middle third of body length; vas deferens with ciliated epithelium formed between two testes and running cephalad in a zigzag manner; pars muscosa much coiled, pars prostatica highly developed.

Ovary submedian 0.68–0.85 mm in diameter, situated to the right side almost equidistant from caudal margin of posterior testis and anterior margin of acetabulum. Shell gland mass behind the ovary; Laurer's canal present opening a little anterior to excretory pore. Vitellaria, lateral extending from middle of oesophagus to anterior margin of acetabulum, coalesce behind the shell gland mass and around genital sucker. Uterus narrow and coiled behind ovary but wide in its forward course which is median. Eggs 0.136–0.17 by 0.068–0.085 mm.

Excretory vesicle large, median, situated between ovary and acetabulum, excretory canals one on each side, intracaecal and almost

parallel to body wall, slightly converging centrad a little behind genital sucker and where they are connected by a transverse canal with a short median branch given off in front to genital sucker and extend as far as middle of oral sucker

Lymphatic system complex highly reticulate throughout the body length

Host—Goat

Habitat—Stomach

Locality—Allahabad (India)

**Remarks**—*Cotylophoron cotylophorum* (Synonym *C. indicum* Stiles and Goldberger, 1910) Fischöder (1901), as already known differs remarkably from all the species of the genus by the presence of a crossing of the excretory and Laurer's canals. *Cotylophoron ovatum* n. sp. resembles *C. minutum* Leiper and *C. selli* Leiper, in the shape of the testes, but it differs from them in the size of the body, in the size and arrangement of the vitellaria and in the shape of the excretory bladder. It also differs from *C. orientalis* n. sp. and *C. elongatum* n. sp. in the size and the shape of the body, in the diameter and position of the genital sucker, in the presence of papillae on the body wall in having entire testes, in the size and arrangement of the vitellaria and in the presence of simple excretory and lymphatic systems. *C. orientalis* n. sp. resembles *C. elongatum* n. sp. in the shape of testes and arrangement of the vitellaria but it differs in the size of the body, position of the testes and in the excretory and lymphatic systems

### Key to the species of the Genus *Cotylophoron*

1. Excretory canal crossing Laurer's canal *C. cotylophorum*  
Fischöder 1901
- Excretory canal not crossing Laurer's canal .. 2
2. Testes smooth 3
- Testes lobed . 4
3. Testes much smaller than acetabulum *C. minutum*  
Leiper, 1910.
- Testes much larger than acetabulum
- (i) longer than broad *C. selli*  
Leiper, 1910.
- (ii) broader than long .. *C. ovatum* n. sp.

- 4 Testes smaller than acetabulum, situated obliquely *C orientalis* n sp.  
 Testes larger than acetabulum, situated in tandem .. *C elongatum* n sp

## EXPLANATION OF FIGURES

- Fig 1 Dorsal view of *Colylophoron ovatum* n sp  
 Fig 2 Transverse section of *C ovatum* n sp passing through the region of genital sucker  
 Fig 3 Dorsal view of *Colylophoron orientalis* n sp  
 Fig 4 Dorsal view of *Colylophoron elongatum* n sp

## EXPLANATION OF LETTERING

a acetabulum, g p genital papilla, g s genital sucker, int intestinal caecum, oes oesophagus, o s oral sucker, ov. ovary, pars m pars musculosa, pars. p pars prostatica, s. g. shell glanes mass, t<sub>1</sub> anterior testis, t<sub>2</sub> posterior testis, ut uterus, vas. ef vas efferens, vt vitellaria

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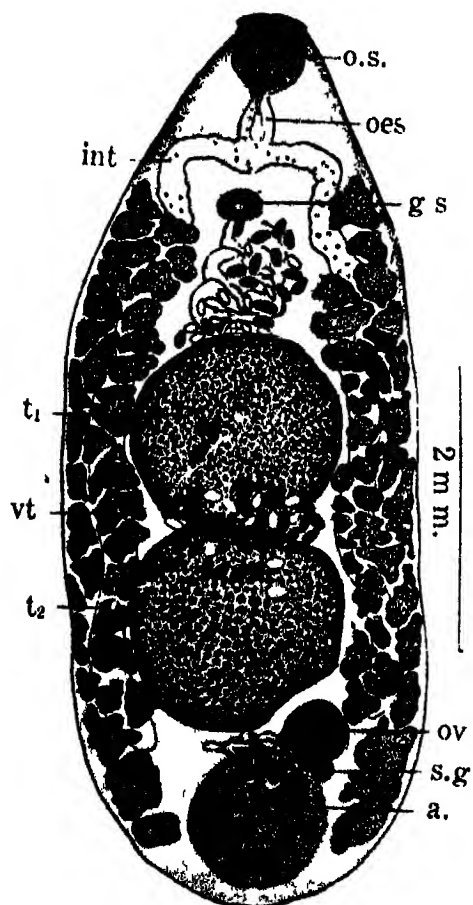


Fig. 1

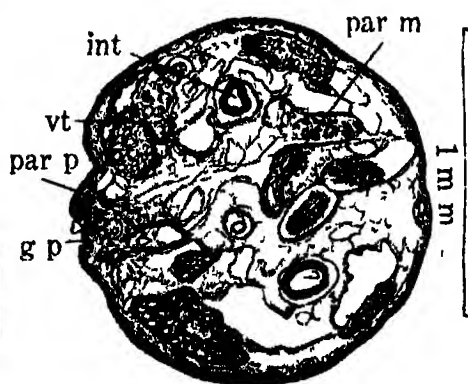


Fig 2

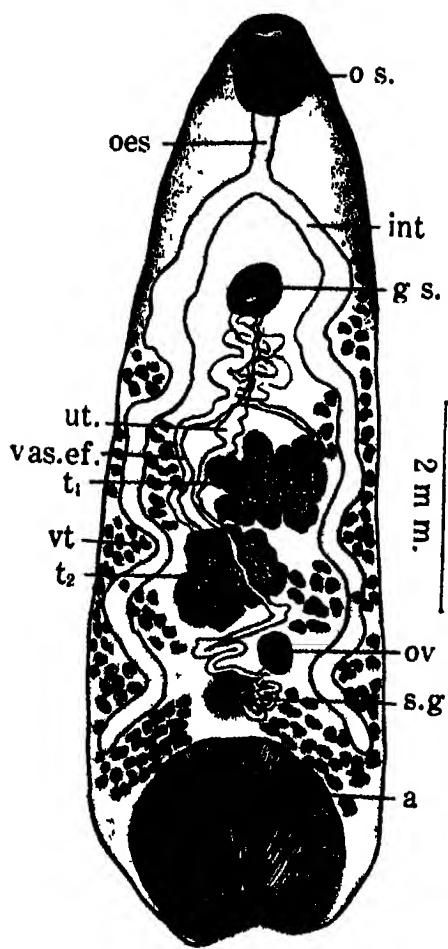


Fig. 3

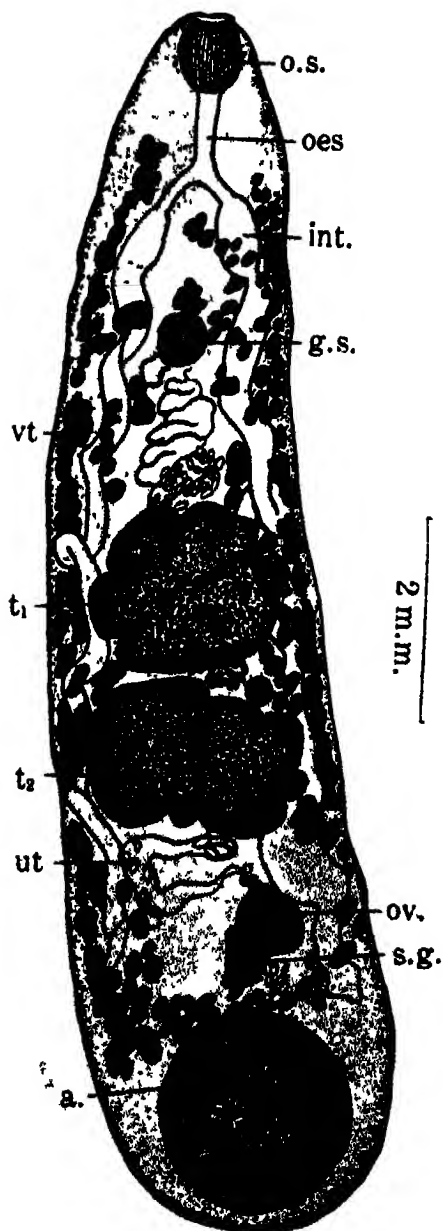


Fig. 4



# ON A NEW TREMATODE FROM AN INDIAN FRESH-WATER FISH

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## Introduction

The trematode described in this paper was found by me in one out of three specimens of a fresh-water fish, *Rita buchanani*, from the river Gomti at Jaunpur, U.P. The parasites, which furnished a new and an interesting species of *Orientocreadium* Tubangui, were about thirty in number. They were picked out after pouring hot water over the intestinal wall to which they were firmly attached. In living condition the anterior end of the worm was seen to be capable of considerable movement while the posterior part filled with a large number of eggs did not show any movement. One specimen of *Opisthorchis pedicellata* Varma was met with in the gall bladder of the second fish.

I am deeply indebted to Dr H R Mehra, under whom I am working for his valuable assistance. I thank Dr D R Bhattacharya for allowing me the reagents and other accessories necessary for field work to Jaunpur, a trip to which place was made in early November, 1933.

## *Orientocreadium indicum*, n. sp.

The distomes are moderately small in size, being 1.9-2.6 mm in length and 0.56-0.66 mm. in maximum breadth which lies in front of equator of the body in the region of the acetabulum. The body is elongated in shape being more tapering at the posterior than at the anterior end. The body-wall is spinose but the distribution of the small backwardly pointed spines is unequal on the body surfaces, those on the ventral side extending little more posteriorly and finally disappearing behind the middle of the posterior testis, while spines on the dorsal side begin to diminish in number near the middle of the ovary being absent altogether posterior to the anterior half of the anterior testis.

The oral sucker, subterminal and circular in outline, measures 0.17–0.21 mm. in diameter with its opening directed towards the ventral surface. The ventral sucker, slightly larger than the oral sucker, measures 0.19–0.23 mm. in diameter and is situated at one-third of the body-length from the anterior end or it may be a little anterior to it. The mouth leads into a well developed prepharynx, followed by a pharynx, 0.1–0.12 x 0.12–0.14 mm. in size and oval in outline. A very short oesophagus, 0.03 mm. long is present. The intestinal caeca terminate slightly in front of the posterior end of the body. Quite a large number of unicellular oval glands with prominent nuclei are present in the anterior part of the body. They lie chiefly lateral to the pharynx and the intestinal caeca in the preacetabular region and are probably of the nature of unicellular cutaneous glands. These glands are also present intercaecally in front of the ventral sucker and around the metratrum.

The excretory pore is situated terminally at the posterior tip of the body. It leads into a simple elongated bag-shaped excretory bladder which extends up to the middle of the posterior testis. The bladder lies, in the region of testis, ventral to it, while posterior to it its position is ventral to the uterus.

The common genital pore lies immediately in front of the acetabulum and is median in position. There is a small genital atrium.

The testes lie in the posterior half of the body one behind the other in the median line. They are dorsally situated and have entire margins. The anterior testis, situated immediately behind shell-gland and measuring 0.25–0.37 x 0.21–0.3 mm. in size, is nearly globular in shape. The posterior testis, larger than the anterior testis, is longer than broad and measures 0.37–0.44 x 0.21–0.28 mm. in size. The cirrus-sac is large and somewhat half-moon shaped. Its greater part lies slightly to the right of the acetabulum. Its posterior end, extending a little beyond the acetabulum, lies slightly in front of the ovary. The structures contained are a somewhat pear-shaped vasculum seminale occupying about one-fourth of its length, a well-developed pars prostatica which is slightly bigger than the vasculum seminale in length, and a long ductus ejaculatorius which is nearly half the length of the cirrus-sac. The space between these structures and the wall of the sac is occupied by prostate gland cells which form a well-developed mass. The long ejaculatory duct is lined internally with forwardly directed spines. A protrusible cirrus is present. Outside the cirrus-sac but lying near its posterior end in the median line between the acetabulum and the ovary and also beside the

latter is the vesicula seminalis externa. It is far greater in size than the vesicula seminalis interna (the ratio in length being 5:2). It may be somewhat coiled in appearance and when it is so its proximal part lies ventral to the anterior end of the ovary.

The ovary, globular in shape, measures 0.19–0.23 mm in diameter and is situated in the posterior part of the anterior half of the body in the median line or a little to the right. Like the testes it is also dorsally placed. The shell gland complex, nearly equatorial in position, lies to the right side of the ovary between its posterior part and the anterior testis. A receptaculum seminis is absent its function being performed by the first few coils of the uterus. The Laurer's canal is present. The uterus, thrown into numerous coils, on emerging from the shell-gland passes to the posterior end of the body. Its coils lie ventral to the testes, the intestinal caeca even extending lateral to the latter with only the vitelline follicles between them and the body wall. On reaching the posterior end the uterus is thrown into similar ascending coils and winds its way forwards lying ventral to the ovary and external seminal vesicle. It ends in a capacious muscular metraterm. The metraterm like the ejaculatory duct is lined internally with relatively large spines and opens externally in the genital atrium. The eggs are numerous, operculated, yellow in colour and measure  $0.031 \times 0.018$  mm in size.

The vitellaria consist of a large number of follicles beginning at the level of the posterior end of the acetabulum and extending behind the blind end of the intestinal caeca terminate at the posterior end of the body, where the follicles from the two sides meet in the midventral line below the excretory bladder. The follicles are confined mainly to the outer side of the acetabulum, caeca and uterine coils. In the region of the posterior testis a few follicles may lie dorsal to the caeca and also they extend to midventral line and unite there below the excretory bladder.

The genus *Orientocercadium* was created by Tubangui in 1931 for the trematode commonly obtained from *Glurias batrachus*, of the Philippine Islands, with *O. batrachoides* as the type species. *O. indicum* is the second species of the genus and the first to be described from India. The points wherein the new species differs from the type species and which are considered specific are.—

1. Presence of unicellular cutaneous glands in the preacetabular part of the body in the new species.

2. Maximum breadth in the pre-equatorial part of the body instead of the post equatorial (as in the case is the type species).

3 Presence of an internal seminal vesicle somewhat pear-shaped in outline (in the type species the large seminal vesicle is located outside cirrus-sac)

4 Ejaculatory duct lined internally with spines unlike the type species

5 Ovary spherical in shape instead of being oval as in the type species

6 Metraterm well-developed and also armed with spines which is not the case in the type species.

7 Vitelline follicles are not united to form a lattice work as we find in the type species, vitellaria extending a little more forwards than in the type species

To accommodate the new species it has become necessary to modify the generic diagnosis of *Orientocrendium*. The emended diagnosis is as follows —

Allocrenidae, small distomes with moderately developed suckers, oral sucker subterminal, acetabulum near one-third of body length from anterior end, cuticle spinose, unicellular cutaneous glands may or may not be present in preacetabular part. Pharynx separated from subterminal mouth by short prepharynx, oesophagus very short, intestinal caeca long reaching to near posterior end of body. Genital pore median, immediately preacetabular. Testes median, tandem, postovarian, postequatorial, cirrus-sac large, muscular, beside acetabulum; seminal vesicle large entirely outside the cirrus-sac or with a small vesicula seminalis interna, pars prostatica well-developed; ductus ejaculatorius long with or without its internal wall lined with spines. Ovary postacetabular, near the median line and pretesticular. No receptaculum seminis, first few coils functioning as sperm-reservoir. Laurer's canal present. Uterus long, reaching to posterior end in descending coils, then turning forwards may or may not end in a metraterm which is armed like ductus ejaculatorius. Vitellaria moderately developed in follicles extending to posterior end of body and anteriorly do not extend beyond acetabulum. Eggs small and numerous. Parasites of fishes.

Type species—*Orientocrendium batrachoides* Tubangui, 1931. Key to the species.—

1. Seminal vesicle lying wholly outside the cirrus-sac—  
*O. batrachoides* Tubangui.
2. Part of seminal vesicle enclosed inside the cirrus-sac—  
*O. indicum* n. sp.

## SYSTEMATIC POSITION

While referring his new genus to the family Allocreadinae Stossich (1904, as emended by Winfield in 1929) Tubangui pointed out that *Orientocreadium* bears a certain resemblance to *Plesiocreadium typicum* Winfield (1929) but differs from it in having its seminal vesicle completely external to the cirrus-sac, in the presence of prepharynx, in having a short oesophagus and in the posterior extent of the vitellaria. He does not say here as to which sub-family his genus fits in. In 1933 he places *Orientocreadium* in the sub-family Allocreadinae Looss 1902.

The strongest point against the inclusion of *Orientocreadium* in Allocreadinae appears to me to be the nature of the uterus which is certainly more extended and the very large number of eggs than is the case in that sub-family.

Since Winfield's description of the type species of *Plesiocreadium*, a second species has been described by Hunter (1932) from fresh-water fish and designated *P. parvum*. In 1932 Van Cleave and Mueller in course of their description of a new species of *Macroderoides* Pearse (1924), *M. flavus*, have considered *Plesiocreadium* as a synonym of *Macroderoides*. But Hunter, after pointing out the differences between his species and the type species, says that "*P. parvum* superficially resembles the genus *Macroderoides*, and a careful study of sectioned material dispels this delusion and reveals more features characteristic of the genus *Plesiocreadium*."

To me it appears that the genus *Orientocreadium* would belong with *Plesiocreadium* to the sub-family *Plesiocreadinae* Winfield. The points of difference pointed by Tubangui in his earlier paper such as the character of the seminal vesicle, the extent of the vitellaria and the presence of prepharynx which are sufficiently important should now be considered in the light of the account of the two new species, one of *Plesiocreadium* and the other of *Orientocreadium*.

In *Plesiocreadium* Winfield (1929, Char. emend., Hunter 1932) the seminal vesicle is large inside cirrus-sac while in *Orientocreadium batrachoides* it is wholly external and in *O. indicum* it is partly internal and partly external. The vitellaria in both the species of *Plesiocreadium* do not extend anteriorly beyond the acetabulum but posteriorly they reach beyond the posterior testis and terminate near the hinder end of the body in *P. parvum* only—a condition which is also met with in the species of *Orientocreadium*. The condition of the vitellaria in *P. parvum* comes nearer to that of the genus *Orientocreadium*. A distinct prepharynx is present in *P. parvum* and not in *P. typicum*. A prepharynx is present

in *Orientocreadium*. The fourth point of difference which remains is about the shortness of oesophagus in *Orientocreadium*.

EXPLANATION OF PLATE (Figs 1—3)

- 1 Ventral view of an extended specimen
- 2 Transverse section through cirrus-sac and external seminal vesicle.
- 3 Transverse section through ventral sucker.

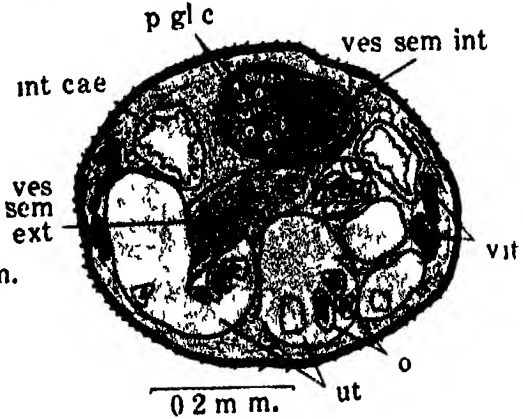
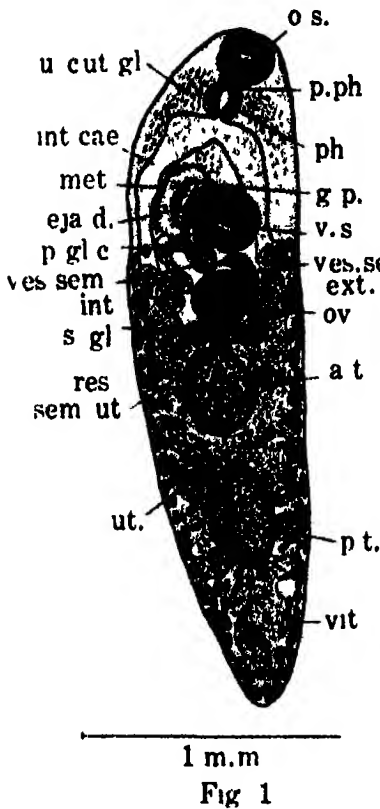


Fig 2

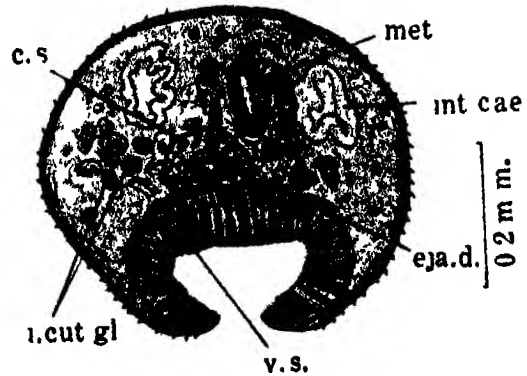


Fig. 3

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# ON NEW TREMATODES OF FROGS AND FISHES OF THE UNITED PROVINCES, INDIA

## Part IV The Occurrence and Seasonal Incidence of Infection of Certain Trematodes in the Above Hosts

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Communicated by Dr H R Mehra

Received December 15 1933

An attempt was made during a short holiday trip to Sitapur, Oudh, in the summer vacation of 1932 to make a collection of Helminths of cold-blooded vertebrates. With a view to augment this and to study the phenomenon of seasonal infection of certain parasites under observation, several trips were subsequently made to Sitapur from time to time. Besides, a large number of frogs and fishes available at Allahabad, Lucknow, Nagina and Garhmukteshwar have also been examined for parasites. From this collection which included Trematodes, Cestodes, Nematodes and Acanthocephala, the trematodes of frogs and fishes, of which the greater majority were new to science and have subsequently been described by me in the first three parts, were selected for special study.

For this work more than 500 hosts have been examined. The common-pond frog *Rana cyanophlyctis* of Sitapur has been found to furnish a large number of interesting Trematodes. The two new species of *Halipegus*, *H. mehranensis* and *H. spindale* were obtained from this frog, one from the stomach and the other from the intestine. In the stomach was also found *Ganeo gastricus* Srivastava. I also obtained three species of *Plenurogenes*, *P. gastroporus* var. *equalis* Mehra and Negi, *P. sitapuri* Srivastava and *P. orientalis* Srivastava and two species of *Prosoloeus*, *P. indicus* Mehra and Negi, and *P. infrequentum* Srivastava from the duodenum of this frog. The intestines were at times found clogged with specimens of *Trematorchis ranarum* Mehra and Negi, *Ganeo tigrinum* Mehra and Negi and *G. attenuatum* Srivastava, while to the walls of the rectum were found firmly attached specimens of a new species of *Diploascus* Dies. Besides an interesting form for which a new genus, *Mehraorchis*, had to be created was obtained from

cysts in the body cavity of the same host. In addition to the forms already reported by Mehra and Negi, *Rana tigrina* of Sitapur was found to harbour a new variety of *Halepegus mehranensis* - var. *minutum*. This host also showed accidental infection with the species of *Diplostiscus* which is commonly parasitic in *R. cyanophlyctis*. All the trematodes which have been described from *R. tigrina* by Mehra and Negi have also been met with in *R. cyanophlyctis*. But an extensive examination of a large number of hosts from different localities showed a marked host specificity in the case of most of the parasites described by me from *R. cyanophlyctis*.

Examination of a large number of specimens of *Ophiocephalus pinnelatus* and *O. striatus* caught at Sitapur, Nagina, Garhmukteshwar, Allahabad and Lucknow yielded two new species of *Progonus*, *P. ovocaudatum* and *P. piscicola*, and two new species of a new genus, *Ophiocorechis*, (*O. lobatum* and *O. singularis*). These hosts were also heavily infected with cysts of *Clinostomum* and *Kuchinosomum* metacercariae found in the body-cavity and *Holostomum* metacercariae found in the pericardial cavity. Specimens of *Schundia gangetica*, a common fish in the river Jumna was found harbouring species of *Gasterosomum* in the digestive tracts and cysts of *Holostomum* metacercariae in its gonads.

Sewell in 1920 showed "that *Mesocoelium social* Lühe is a common inhabitant of *Bufo melanostictus* during the months of May and June but apparently totally disappears at other times of the year. A similar annual rise and fall occurs in the case of *Fasciola hepatica*, though a few individual flukes may remain in the liver of the affected sheep and it is possible that many trematodes may show the same seasonal variation". The larvae also are seasonal in their appearance as has already been pointed out by Leiper in 1915, Kemp and Gravelly in 1919 and Sewell in 1920. I have studied the seasonal incidence of infection of certain trematodes in *R. cyanophlyctis* and my observations support the above remark of Sewell. For a study of seasonal incidence of infection it is absolutely necessary that one should confine one's attention to a certain definite locality, for, as has been observed by me, the degree of infection may and often does vary enormously in the same host species obtained from different localities. A remarkable instance of this is found in the fact that whereas specimens of *R. cyanophlyctis* from Sitapur are found heavily infected with a large number of trematodes, those from Allahabad in the same season rarely show any infection at all. During the course of my investigation I have noted the maximum degree of infection as well as the time of the year of such infection. I have found enormous variations in the intensity of infection



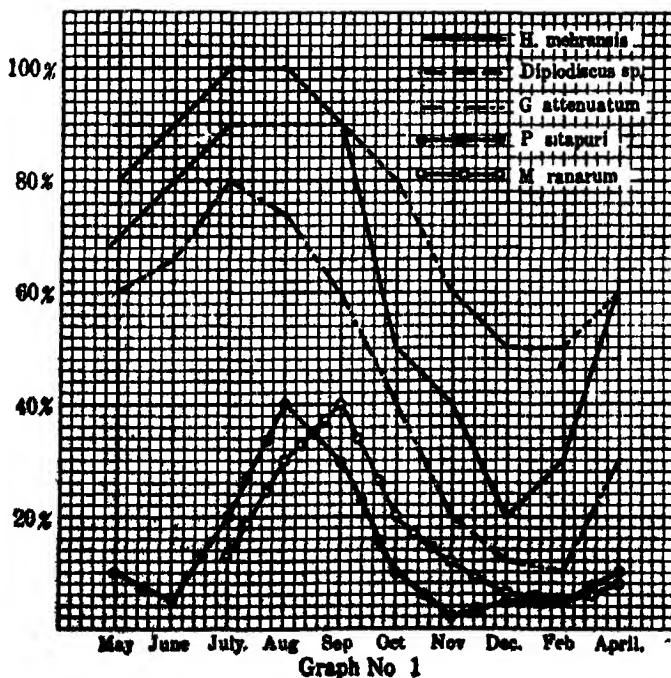
with different seasons in the case of five trematodes (*Halipegus mehranensis*, *Diplostiscus* sp, *Ganeo attenuatum*, *Mehraorchis ranarum* and *Plourogenes sitapuri*) even though the hosts were always taken from the same locality. In Graph No. 1 I have given the results obtained by me from an examination of hosts from Sitapur District at different times of the year. The curves show that the maximum rise in the intensity of infection occurs during the rainy season and the maximum fall in winter months. Graph No 2 shows the maximum frequency of occurrence in the case of the new trematodes that I have studied.

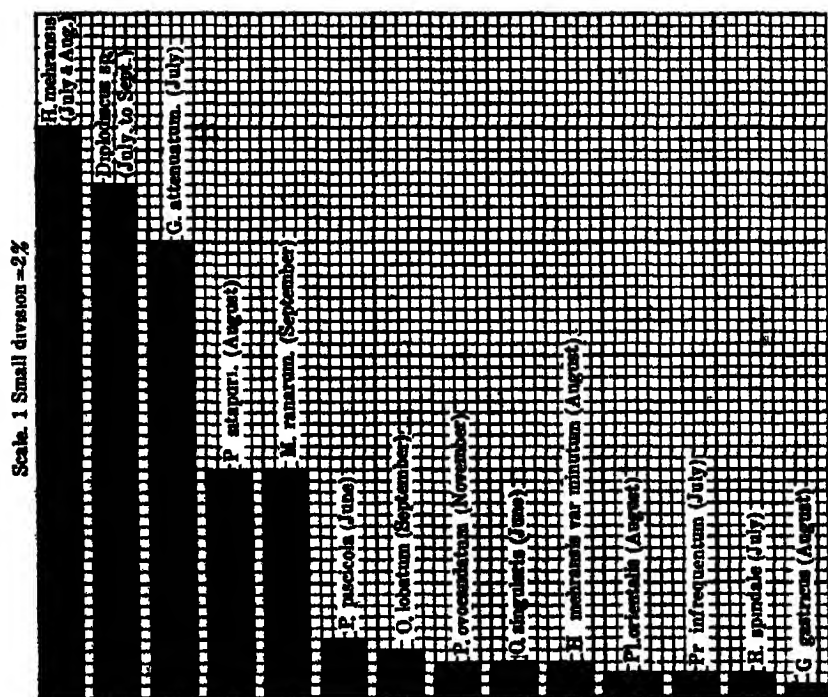
I am greatly indebted to Dr H R Mehra, for his valuable help and advice and to Dr D R Bhattacharya for providing me laboratory facilities during holidays and giving me reagents and other requisites for field collection. I take this opportunity of expressing my deep indebtedness to my brother, Mr Girja Dayal Srivastava, who has very kindly provided me with a regular supply of the hosts from Sitapur, Lucknow, Nagina and Garhmukteshwar for parasitological examination.

#### EXPLANATION OF GRAPHS

Graph.—No 1. Showing Seasonal Incidence of Infection

Graph —No 2 Showing the maximum Frequency of Infection





Graph No. 2

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## ADDENDUM

Since the communication of the above paper for publication in the Proceedings, Academy of Sciences, U P, Allahabad, Tubangui's paper on "Trematode Parasites of Philippine Vertebrates, VI" has been received in the Department. In this paper the author gives an account of a new species of *Diplodiscus*—*D. amphichrus*. In the general topography of its organs and the position of the genital pore Tubangui's species resembles very closely the Indian species referred to in my above paper. The Indian representative, however, presents many important and constant points of difference from *D. amphichrus*, such as, the larger size of its body and the various organs (Table 1), presence of well developed glands round the oesophagus, the character of the oesophageal bulb which is conspicuous and well developed and the disposition of the vitellaria which do not meet mesially in front of the genital pore. These differences are sufficiently important to warrant the creation of a new variety for the Indian species—*D. amphichrus*—var *magnum* n var

Table I

	Length	Maximum breadth	Length of oesophagus	Size of Oral sucker	Size of Oral pouches	Size of oesobulb	Diameter of Acetabulum
<i>D. amphichrus</i> Tubangui ..	1.6-3.3*	0.6-0.86	0.27-0.44	0.11-0.26	0.11-0.26	Inconspicuous	0.5-1.08
<i>D. amphichrus</i> var <i>magnus</i> N Var	2.6-6.7	1.2-2.1	0.26-0.56	0.35-0.56	0.1-0.2	0.1-0.26 x 0.1-0.17	0.87-1.5
	Accessory sucker	Testis	Cirrus sac	Position of genital pore	Ovary	Eggs	
<i>D. amphichrus</i> Tubangui	0.1-0.13	0.14-0.46	0.12-0.22	Close behind the anterior third of body length	0.12-0.24	104-112 x 62.4-70.7 microns	
<i>D. amphichrus</i> var <i>magnus</i> N Var	0.17-0.35	0.37-0.7	0.1-0.15	Do	0.17-0.4	0.12-0.14 x 0.05-0.7 m m	

Fig 1 Ventral view of *Diplodiscus amphichrus* var *magnus*

## LETTERING

O. s — Oral sucker. O p — Oral pouch Oes — Oesophagus Oes. gl — Oesophageal glands. Oes b — Oesophageal bulb C. s. — Cirrus sac. G p — Genital pore Eg — Eggs

Int. c — Intestinal caecum T — Testis Vit. — Vitellaria. Ov. — Ovary. S g — Shell gland. Acet — Acetabulum Acc s — Accessory sucker, i.e., a sucker-like structure in the centre of the acetabulum

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\* All measurements are in mm.

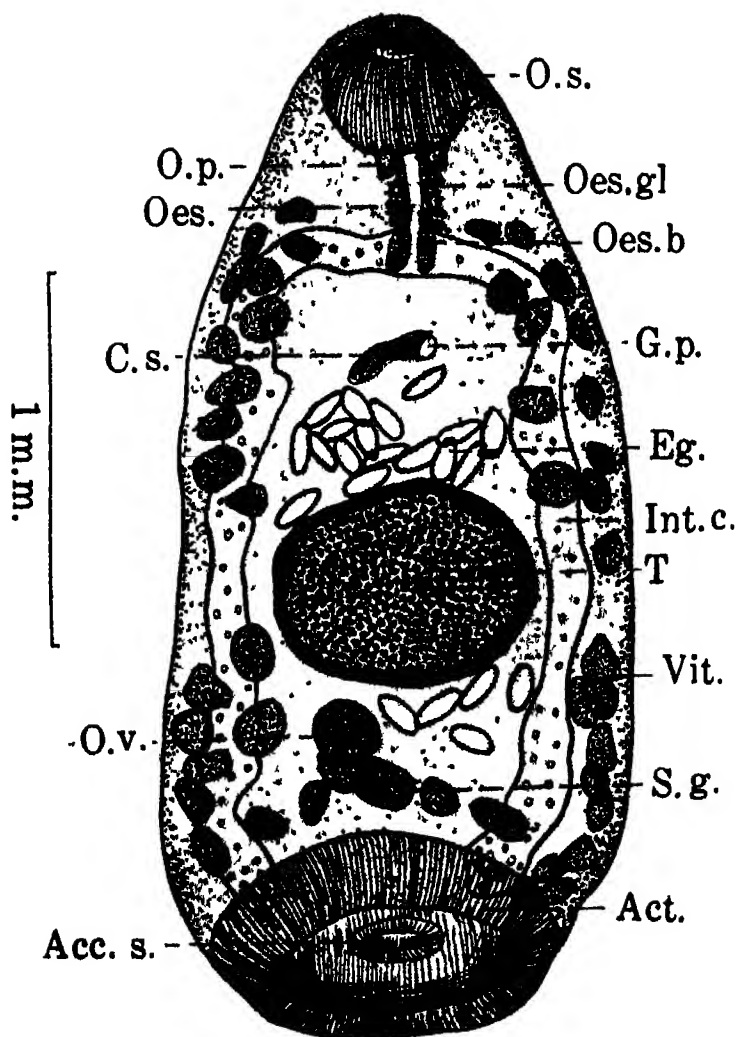


Fig. 1

**Errata to Part I Published in the Bull. Acad. Sci. U. P.,  
Vol 3, No 1, pp. 41—60, 1933.**

Page 41, line 5 from bottom, for sids read sides

Page 47, line 7, for vntral read ventral

Page 48, line 13 from bottom, delete " with a polar filament at the posterior end "

Page 48, line 11 from bottom, after " uterine coils " add, " the presence of polar filament (in *Halipegus*) "

Page 57, line 5, for (Figs 7 & 8) read (Fig 7)

Page 58, lines 3, 4, 5, 6 & 9 (Figs 1, 4, 5, 6, 7), from bottom, for ventral read dorsal

*Note on species of Halipegus Looss, 1899*

The copulatory apparatus of the species of *Halipegus* described by me in Part I is very much like that of most Hemiurids. The voluminous vesicula seminalis is continued into a tubular pars prostatica which is surrounded by numerous prostate gland cells lying free in the parenchyma. Terminally the pars prostatica opens through a fairly long ductus ejaculatorius into the highly muscular metraterm. The well developed ductus hermaphroditicus is protrusible and opens on a conical papilla in the genital atrium.

In a joint paper, "Fauna Helminthologica Dos Peixes De Agua Doce Do Brasil" Separado Do Volume 1, Dez 1928, Dos Archiv. Do Instituto Biologico, Sao Paulo, Travassos, Artigas and Pereira have described three species of *Genarchella* N. Gen. from Brazilian fishes. The genus does not differ in any character, which might be considered of generic importance, from *Halipegus* Looss and should, therefore, be considered synonymous with the latter.

# PROCEEDINGS

## OF THE

# ACADEMY OF SCIENCES

(UNITED PROVINCES OF AGRA AND OUDH, INDIA)

Part 2 ]

November 1934

[ Volume 4

### CONTINUOUS DEFORMATION OF RULED SURFACES

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1. The object of this paper is to prove both by vector methods and directly that when a ruled surface is continuously deformed into an applicable ruled surface,  $K_n \cos \theta + T_g \sin \theta$  is an invariant, where  $K_n$  and  $T_g$  are the normal curvature and the geodesic torsion of the curve, and  $\theta$  is the angle which the generator makes with the tangent to the curve.

I am much indebted to Prof. C H Rowe of Trinity College, Dublin, for his assistance and guidance in obtaining the results of this paper

2 Let

$v \equiv$  unit vector along generator,

$t \equiv$  unit vector along tangent to base curve,

$n \equiv$  unit vector along normal to base curve in the tangent plane,

then  $v = t \cos \theta + n \sin \theta$

$$\frac{dv}{ds} = \frac{dt}{ds} \cos \theta + \frac{dn}{ds} \sin \theta + t (-\sin \theta \theta') + n (\cos \theta \theta')$$

Let  $v$  be unit vector along normal to surface, then we get

$$v \cdot \frac{dv}{ds} = \cos \theta \ v \cdot \frac{dt}{ds} + \sin \theta \cdot v \cdot \frac{dn}{ds} = K_n \cos \theta + T_g \sin \theta,$$

where ' $\cdot$ ' indicates scalar product and where  $K_n$  and  $T_g$  are respectively the normal curvature and the geodesic torsion.

Hence  $K_n \cos \theta + T_g \sin \theta$ , i.e.,  $\frac{\cos \omega}{\rho} \cos \theta + \left( \frac{1}{\sigma} + \omega' \right) \sin \theta$  is the component normal to the surface of the rate of change per unit arc of a unit vector along the generator

Now taking the curve as the base curve, the equations of the ruled surface in the usual notation are given by  $x = p + lu$ ,  $y = q + mu$ ,  $z = r + nu$ , the origin being the point  $P(p, q, r)$  on the base curve

We know that  $ds^2 = du^2 + 2 \cos \theta \, du dv + (Au^2 + 2Bu + 1) dv^2$ , where  $\cos \theta = \Sigma l p'$ ,  $A = \Sigma l'^2$ ,  $B = \Sigma l' p'$ ;  $l, m, n$  being taken as a unit vector

$$v \text{ is the vector } \left( \frac{mx' - ny'}{\sin \theta}, \frac{nx' - lz'}{\sin \theta}, \frac{ly' - mx'}{\sin \theta} \right),$$

$\frac{dv}{ds}$  is the vector  $(l', m', n')$ .

$$\text{Hence } v \bullet \frac{dv}{ds} = \frac{1}{\sin \theta} \begin{vmatrix} l' & m' & n' \\ l & m & n \\ x' & y' & z' \end{vmatrix}$$

$$\text{But } \begin{vmatrix} l' & m' & n' \\ l & m & n \\ x' & y' & z' \end{vmatrix}^2 \equiv \begin{vmatrix} l & m & n \\ l' & m' & n' \\ x' & y' & z' \end{vmatrix}^2 = \begin{vmatrix} 1 & 0 & \cos \theta \\ 0 & \Sigma l'^2 & \Sigma l' x' \\ \cos \theta & \Sigma l' x' & 1 \end{vmatrix}$$

which is clearly unaltered by deformation, since  $\theta$ ,  $\Sigma l'^2$ , and  $\Sigma l' x'$  are unaltered

$\therefore v \bullet \frac{dv}{ds}$  is an invariant and hence  $K_n \cos \theta + T_g \sin \theta$  is an invariant.

3 Forsyth<sup>1</sup> has obtained the two equations

$$\frac{\sin \omega}{\rho} = -\theta' - \frac{B}{\sin \theta}, \quad \text{and}$$

$$A - B^2 = \left\{ \frac{\cos \theta}{\rho} - \frac{\sin \theta \cos \omega}{\sigma} + \frac{d}{dv} (\sin \theta \sin \omega) \right\}^2 + \left\{ \frac{d}{dv} (\sin \theta \cos \omega) + \frac{\sin \theta \sin \omega}{\sigma} \right\}^2.$$

From the first equation he has deduced that when the surface is deformed, generators remaining straight, the geodesic curvature of the directrix curve viz.  $\frac{\sin \omega}{\rho}$  remains unaltered, but he has not simplified the second equation any further.

We shall show that when the differentiations involved in the second equation are performed, the fact that  $A$  and  $B$  remain unaltered by



deformation ultimately leads to the invariant  $K_n \cos \theta + T_g \sin \theta$  which has been obtained in § 2 by vector methods

Let the direction cosines of the tangent, principal normal and binormal to the curve at P be  $l_1, m_1, n_1, l_2, m_2, n_2, l_3, m_3, n_3$  respectively. Then if  $\omega$  denotes the angle between the principal normal to the curve and normal to the surface at P, the direction cosines of the normal to the surface at P are  $l_2 \cos \omega + l_3 \sin \omega, m_2 \cos \omega + m_3 \sin \omega, n_2 \cos \omega + n_3 \sin \omega$ .

$$\therefore l = l_1 \cos \theta + (-l_2 \sin \omega + l_3 \cos \omega) \sin \theta$$

$$\therefore l' = \cos \theta \left( \frac{l_2}{\rho} - l_1 \sin \theta \theta' - \sin \omega \sin \theta \left( \frac{l_3}{\sigma} - \frac{l_1}{\rho} \right) \right.$$

$$\left. + \cos \omega \sin \theta \left( -\frac{l_2}{\sigma} \right) \right.$$

$$\left. - l_2 (\sin \omega \cos \theta \theta' + \cos \omega \sin \theta \omega') + l_3 (\cos \omega \cos \theta \theta' - \sin \theta \sin \omega \omega') \right)$$

$$= l_1 \left( -\sin \theta \theta' + \frac{\sin \omega \sin \theta}{\rho} \right) + l_2 \left( \frac{\cos \theta}{\rho} - \frac{\cos \omega \sin \theta}{\sigma} \right.$$

$$\left. - \sin \omega \cos \theta \theta' - \cos \omega \sin \theta \omega' \right)$$

$$+ l_3 \left( -\frac{\sin \omega \sin \theta}{\sigma} + \cos \omega \cos \theta \theta' - \sin \theta \sin \omega \omega' \right)$$

$$\therefore B \equiv \Sigma l' p' = \Sigma l' l_1 = -\sin \theta \theta' + \frac{\sin \omega \sin \theta}{\rho} = \sin \theta \left( \frac{\sin \omega}{\rho} - \theta' \right)$$

$$A \equiv \Sigma l'^2 = \left( -\sin \theta \theta' + \frac{\sin \omega \sin \theta}{\rho} \right)^2 + \left( \frac{\cos \theta}{\rho} - \frac{\cos \omega \sin \theta}{\sigma} \right.$$

$$\left. - \sin \omega \cos \theta \theta' - \cos \omega \sin \theta \omega' \right)^2$$

$$+ \left( \frac{-\sin \omega \sin \theta}{\sigma} + \cos \omega \cos \theta \theta' - \sin \theta \sin \omega \omega' \right)^2$$

$$= \theta'^2 + \frac{\cos^2 \theta}{\rho^2} + \sin^2 \theta \left( \omega'^2 + \frac{2}{\sigma} \omega' + \frac{1}{\sigma^2} + \frac{\sin^2 \omega}{\rho^2} \right) - \frac{2}{\rho} \theta' \sin \omega$$

$$- \frac{2 \cos \theta \cos \omega \sin \theta}{\rho} \left( \frac{1}{\sigma} + \omega' \right)$$

$$= \theta'^2 - \frac{2}{\rho} \theta' \sin \omega + \sin^2 \theta \left[ \frac{\sin^2 \omega}{\rho^2} + \left( \frac{1}{\sigma} + \omega' \right)^2 + \frac{\cot^2 \theta}{\rho^2} \right.$$

$$\left. - \frac{2 \cot \theta}{\rho} \cos \omega \left( \frac{1}{\sigma} + \omega' \right) \right].$$

If the surface is deformed in such a way that the generators remain straight, then  $\theta = \text{const.}$ , and A and B remain unaltered.

$\therefore \frac{\sin \omega}{\rho}$ , and  $\left( \frac{1}{\sigma} + \omega' \right)^2 + \frac{\cot^2 \theta}{\rho^2} - \frac{2 \cot \theta}{\rho} \cos \omega \left( \frac{1}{\sigma} + \omega' \right)$  are invariants.

This second invariant can also be written as  $\left( \frac{1}{\sigma} + \omega' \right)^2$

$$+ \frac{\cot^2 \theta \cos^2 \omega}{\rho^2} + \frac{\cot^2 \theta \sin^2 \omega}{\rho^2} - \frac{2 \cot \theta \cos \omega}{\rho} \left( \frac{1}{\sigma} + \omega' \right)$$

since  $\frac{\sin^2 \omega}{\rho^2}$  is an invariant, it follows that  $\left[ \left( \frac{1}{\sigma} + \omega' \right) \right.$

$\left. + \frac{\cot \theta \cos \omega}{\rho} \right]^2$  is an invariant and hence that

$\frac{\cos \omega}{\rho} \cos \theta + \left( \frac{1}{\sigma} + \omega' \right) \sin \theta$  is an invariant.

Cor. 1 For an orthogonal trajectory of the generators  $\theta = \frac{\pi}{2}$ , and

hence  $\frac{1}{\sigma} + \omega'$ , i.e., the geodesic torsion is also an invariant

Cor. 2. When  $\frac{\sin \omega}{\rho}$ ,  $K_n \cos \theta + T_g \sin \theta$ , and  $\theta$  remain unaltered,  $ds^2$  remains unaltered. Hence:—

The conditions that  $\frac{\sin \omega}{\rho}$ ,  $K_n \cos \theta + T_g \sin \theta$ , and  $\theta$  remain unaltered are sufficient conditions that the ruled surfaces be applicable

### Reference

- 1 Forsyth, *Differential Geometry*, p 392

# NOTE ON THE CONVERGENCE OF THE CONJUGATE SERIES OF A FOURIER SERIES

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1. The object of this note is (i) to give a correct proof of a convergence theorem for the conjugate series of a Fourier series contained in Hobson's *Theory of Functions of a Real Variable*, the proof, as given by Hobson, being faulty, and (ii) to clear a misunderstanding which might arise from a note published in the *Bulletin of the Calcutta Mathematical Society*.

2 In his book referred to above, Hobson has proved<sup>1</sup> that if at a point of continuity of the function  $f(x)$ , the function be of bounded variation in some neighbourhood of  $x$ , the conjugate series converges at  $x$ , to the value

$$\lim_{n \rightarrow \infty} \frac{1}{2\pi} \int_{\frac{\pi}{n}}^{\pi} \{ f(x+t) - f(x-t) \} \cot \frac{1}{2} t \, dt,$$

provided this limit has a definite value.

<sup>1</sup> Hobson, I, 694-696.

The proof, however, of the above theorem as given by Hobson, is faulty, inasmuch as it contains a slip in the application of the second mean value theorem in the step<sup>1</sup>

$$\int_{\frac{\pi}{n}}^{\delta} P(t) \cot \frac{t}{2} \cos nt \, dt = \cot \frac{\pi}{2n} P\left(\frac{\pi}{n}\right) \int_{\frac{\pi}{n}}^{\delta'} \cos nt \, dt$$

For, if, as taken in the proof,  $P(t)$  is monotone *non-increasing* and  $P\left(\frac{\pi}{n}\right)$  tends to zero, as  $n \rightarrow \infty$ , then  $P(t)$  must be, in general, negative in  $\left(\frac{\pi}{n}, \delta\right)$  and the mean value theorem in the form as used there, will not be applicable

In order to remedy this defect I give below the following modified proof.—

Let

$$\psi(t) = f(x+t) - f(x-t) = \psi_1(t) - \psi_2(t),$$

where each of  $\psi_1(t)$  and  $\psi_2(t)$  is a positive, monotone, non-diminishing function of  $t$  and let

$$\lim_{t \rightarrow 0} \psi_1(t) = A, \quad \lim_{t \rightarrow 0} \psi_2(t) = B$$

Since  $\lim_{t \rightarrow 0} \psi(t) = 0$ , we have  $A = B$  Then

$$\psi(t) = \{\psi_1(t) - A\} - \{\psi_2(t) - B\} = P_1(t) - Q_1(t), \text{ say} \quad \text{Now}$$

$$\begin{aligned} & \int_{\frac{\pi}{n}}^{\delta} P_1(t) \cot \frac{t}{2} \cos nt \, dt \\ &= \cot \frac{\pi}{2n} \int_{\frac{\pi}{n}}^{\delta'} P_1(t) \cos nt \, dt \quad \cdot \quad \frac{\pi}{n} \leq \delta' \leq \delta \\ &\leq \cot \frac{\pi}{2n} \cdot \frac{2}{n} P_1(\delta') \end{aligned}$$

Since corresponding to an arbitrarily small positive number  $\varepsilon$ ,  $\delta$  can be chosen so small (and  $n$  sufficiently large so that  $\frac{\pi}{n} < \delta$ ) that in  $(0, \delta)$

<sup>1</sup> *Ibid.* 695.

$$P_1(t) < \frac{\varepsilon}{\cot \frac{\pi}{2n}, \frac{1}{2}},$$

we get

$$\lim_{n \rightarrow \infty} \int_{\frac{\pi}{n}}^{\delta} P_1(t) \cot \frac{t}{2} \cos nt \, dt = 0$$

A similar result holds for the function  $Q_1(t)$ . Hence

$$\lim_{n \rightarrow \infty} \int_{\frac{\pi}{n}}^{\delta} \psi(t) \cot \frac{t}{2} \cos nt \, dt = 0$$

3. Sometime back I published in the *Bulletin of the Calcutta Mathematical Society*<sup>1</sup> a paper entitled "Direct proof of Young's theorem for the convergence of the conjugate series of a Fourier series" and in the same issue there appeared a note<sup>2</sup> entitled "Addition to the paper 'Direct proof of Young's theorem for the convergence of the conjugate series of a Fourier series'" By some mistake I am shown as the author of this note. The note runs as "Miss Sargent also gives a direct discussion<sup>3</sup> on lines similar to those in my paper, although she starts with Young's criterion in a *different* form" This is incorrect and misleading inasmuch as it gives the impression that for the convergence of the conjugate series there is only *one* criterion of Young whose direct proof has been given on similar lines both by myself and by Miss Sargent and that we have started with different forms of this Young's criterion. The fact is that Young has given *more than one*<sup>4</sup> criterion for the convergence of the conjugate series, and the criterion whose proof is given by Miss Sargent is entirely different from that criterion of Young whose direct proof is given by me, because these two criteria are *quite independent of each other and mutually exclusive*. The criterion whose proof is given by Miss Sargent is the analogue, for the conjugate series, of *Young's test* for the convergence of Fourier series, while the criterion whose proof is given by me is the analogue of *De la Vallée-Poussin's test*, and it is well-known that these two criteria are different and independent of each other.

<sup>1</sup> *Proceed.* 2.

<sup>2</sup> p. 161.

<sup>3</sup> *Sargent*, 3.

<sup>4</sup> *Young*, 4, 5.

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- 1 E W Hobson, *The Theory of Functions of a Real Variable*, Vol 2, ed. 2, Cambridge (1926),
- 2 B N Prasad, "Direct proof of Young's theorem for the convergence of the conjugate series of a Fourier series" *Bulletin of the Calcutta Math. Soc.*, 24 (1932), 137—142
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- 4 W H Young, "Konvergenzbedingungen für die verwandte Reihe einer Fourierschen Reihe," *Münchener Sitzungsberichte*, 41 (1911), 361—371
- 5 ———, "On the convergence of the derived series of a Fourier series" *Proc London Math Soc* (2), 17 (1918), 195—236

# IONOSPHERIC HEIGHT MEASUREMENT IN THE UNITED PROVINCES OF AGRA AND OUDH

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Received August 2, 1934

Although nearly a quarter of a century earlier Balfour Stewart anticipated Kennelly and Heaviside, the last two scientists in 1902 gave a definite suggestion about the presence of an ionised layer in the upper atmosphere at the height of approximately 60 to 80 km. A definite experimental proof of the existence of such a layer was, however, lacking till 1925, when Appleton<sup>1</sup> definitely proved the presence of down coming wireless waves from the upper atmosphere. Since then various investigators all over the world have been studying the state of the upper atmosphere by projecting radio waves upwards and examining the condition of the down coming waves.

Out of the methods that have so far been used for the study of the upper atmosphere, the method of radio sounding has been the most successful method. In addition to the well known Kennelly-Heaviside layer situated at about 100 km height, which is known as the H-layer, in 1930 Appleton<sup>2</sup> decisively proved the existence of another layer 'F'—also known as the Appleton layer—at a height of about 200 km. The existence of such a layer was, however, obtained by Breit and Tuve,<sup>3</sup> in 1930, but they erroneously explained it as a multiple reflection. Lately the presence of various other layers, or so to say the fine structure of the ionosphere, has been detected by Schafer and Goodall<sup>4</sup> in America and Appleton<sup>5</sup> and co-workers in England.

In India pioneering work in this line has been done by Prof. Mitra<sup>6</sup> and his students. Verman,<sup>7</sup> at Bangalore, is also reported to have done something, but we have not come across a full account. Though considerable amount of work has been done on the subject in various countries, very little has been done in India. With a view of making a thorough study of the ionosphere throughout the year, the present work has been undertaken and the following is to be regarded as only a preliminary report.

There are two methods which have been largely used for the measurement of the height of the Heaviside layer Prof Appleton and his colleagues upto the year 1931, were using mostly the frequency change method, and the Americans have almost exclusively used the Breit and Tuve's group retardation method. Both the methods give in fact the same value of the equivalent height of the ionosphere

Lately Prof. Appleton and his collaborators have also begun using the group retardation method of Breit and Tuve, and the main difference between the two schools is now only in the method of producing pulses. The Americans generally use a mechanically driven chopper, while in England and elsewhere also, the grid choking method similar to the one which is responsible for producing "howling" at the threshold of oscillations in a simple regeneration receiver, introduced by Appleton and Builder<sup>6</sup> is in common use

In this method which has been fully explained by Appleton and Watson Watt, the oscillations are produced in the ordinary way, and during the short interval of about  $10^{-4}$  seconds, owing to the charging up of the grid condenser a grid current is established in the leak resistance, so that the grid is at a high negative potential with respect to the filament and the condition for the maintenance of oscillations is no longer valid, consequently the oscillations cease. Since the leak resistance is about 4 to 5 megohms, it takes a considerable time before the valve again goes into oscillations. The duration of oscillation depends upon the value of the condenser in the grid circuit, while the quiescent period depends upon the C-R value

The transmitter used in the present investigations was constructed in the laboratory.

A horizontal doublet was used for the transmission of the signals, and the energy from the tank circuit of the oscillator was fed to the aerial by means of a feeder line

When we were just thinking about the location of a receiving station, Rai Amarnath Agarwal offered us a very nice room at his residence in Daragun, which is about 2 miles from our transmitter. It was mainly due to Mr Agarwal's ungrudging help and cooperation that the receiving station could be so nicely erected in a very short time. A half wave horizontal aerial was erected for the purpose, and a four stage receiver was employed for the detection of the signals. The receiver consisted of two screengrid H. F. amplifiers, one anode bend detector, and a pentode low frequency amplifier. The oscillograph was connected across a resistance in the anode of the pentode.



75 metre wavelength was used during the present investigation. Sixty pulses per second of  $3.8 \times 10^{-4}$  seconds duration were transmitted. The signals were received in the transmission room on a crystal receiver and the low frequency note was checked against a sixty cycle electrically maintained tuning fork. The necessary changes in the number of pulses was made by varying the current in the filament of the diode.

A linear time base was obtained by using a neon bulb and a saturated diode. The pattern seen on the cathode ray oscillograph screen was made stationary by synchronising the time base with the received signal. The distance between the ground ray and the various reflected waves was measured by means of a dividers and a scale.

Observations were taken both at Daragunj and in the laboratory at different times and on different days, and a set of typical observations are recorded below.

13th May—18 30—20 00 I. S. T

The equivalent height of the E layer was found to be 135 km and usually 4 multiple reflections and sometimes as many as 6 reflections were detected. Between 19 00 and 19 30 I. S. T the intensity of the first reflection, at times, was about two to three times the intensity of the ground ray, but this intensity lasted for only about 3–5 seconds. Between 19 15 and 19 20 the intensity of the second reflection was found on two occasions to be from 3 to 4 times that of the ground pulse, although the intensity of the first reflection was only about half that of the ground ray. No reflection of F Layer could be detected.

14th May—05 30—06 30 I. S. T

The E layer was not detected, but the equivalent height of the F layer was found to be 270 km in the beginning, which gradually fell to about 250 km. Four reflections were usually found, the first was always the strongest, and sometimes its intensity became as strong as that of the ground ray.

The distances between the various reflections were always equal thus showing the presence of multiple reflections. The first reflection was often resolved into two very close peaks owing to the presence of the right-handed and left-handed polarised components as demanded by the magneto-ionic theory. But the distance between the two could not be accurately measured, since the two peaks were very short-lived.

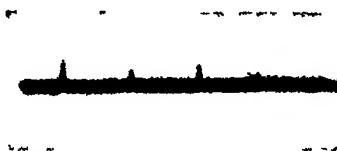
No echoes could be detected at noon and sometimes in the afternoon as well.

It was possible to detect 3 to 4 echoes directly under the transmitting aerial by loosely coupling the tank circuit of the transmitter to the receiver. Later on by increasing the sensitivity of the receiver it was possible to detect the echoes by using a small ordinary untuned receiving aerial situated directly under the transmitting aerial, but placed at right angles to it.

It will be interesting to point out here that Mitra and Rakshit reported that they could not detect reflection unless they moved about a mile from the transmitter and that too only about an hour before sunset. In fact they report that both the intensity as well as the number of multiple echoes increase as the receiver is moved away from the transmitter. They ascribe this to an absorbing effect of the more efficient transmitting aerial. In contrary to this our observations definitely show the presence of multiple echoes during the night as well as in the morning, both under the transmitting aerial as well as at a distance from it.

The necessary apparatus is now under construction for a thorough study of the ionosphere and will be reported later.

Our hearty thanks are due to Rai Amarnath Agarwal who was kind enough to place his room and other things at our disposal. To Prof M N Saha we are grateful for his very keen interest and suggestions throughout the progress of the work.



Typical Photograph of Multiple Echoes

### References

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3. Breit and Tuve, *Proc Inst Rad Eng*, 16, 1236, 1928.
4. Schafer and Goodall, *Ibid.*, 20, 1131, 1932.
5. Appleton, *Phy Soc.*, 44, 76, 1932.
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8. Appleton and Builder, *Nature*, June 27, 1931.

# CHEMICAL EXAMINATION OF THE SEEDS OF *ISABGHOL*, "*PLANTAGO-OVATA*" FORSKS

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*Plantago Ovata*, commonly known as *Isabghol* in Hindustani and Bangali is a plant of the natural order Plantaginæ, and is a well-known medicinal plant of long use in India. "The seeds are boat shaped, about  $\frac{1}{8}$  of an inch long and rather less than  $\frac{1}{16}$ " broad, translucent with a pinkish tinge and a faint brown streak upon the convex side, the concavity is covered with a thin white membrane. Soaked in water they become coated with an abundant adhering mucilage, which is free from taste and odour. The epidermis of the seeds is composed of polyhedral-cells, the walls of which are thickened by secondary deposits, the source of mucilage between it and the albumen is a thin brownish layer. The albumen is formed of thick walled cells, which contain granular matter."

As regards its medicinal properties the crushed seeds, made into a poultice with vinegar and oil are applied to rheumatic and gouty swellings. With the mucilage a cooling lotion for the head is made. Two to three drams moistened with hot water and mixed with sugar are given in dysentery, and irritation of the intestinal canal. The decoction is prescribed in cough. The roasted seeds have an astringent effect and are useful in irritations of the bowels in children and in dysentery. They are considered to be cooling and demulscient and are useful in inflammatory and bilious derangement of the digestive organ. The seeds have also been found serviceable in febrile, catarrhal and renal affections but their chief use is in dysentery. The most important use of the drug is, however, in chronic diarrhoea and dysentery especially in peculiar form of intestinal irritation known as hill-diarrhoea.

So far no work of a chemical nature has been done on the seeds of this highly important indigenous medicinal plant. The only thing said about it in literature is that there is present a large amount of mucilage in the seeds of *Isabghol*. The present authors were, therefore, tempted to submit the seeds to a systematic chemical analysis and isolate the active

principle from it. No alkaloid, or glucoside could be detected during the investigation. The investigation has, however, proved the presence of 5% pale yellow semi-drying oil, large amount of mucilaginous mass, a quantity of inorganic ash and reducing sugars. The oil is worked up in details and its constitution has been described in the experimental part of the paper.

### EXPERIMENTAL

The dried seeds of *Isabgol* were purchased from the local market and were crushed to a fine powder in a crushing machine.

After extracting twenty grammes of the material with dilute hydrochloric acid, the alkaloidal reagents were applied but no alkaloid could be detected.

*Test for Enzymes* —No enzyme body could be detected in the powdered drug.

The powdered seeds when completely burnt in a porcelain dish left 5.0 % of ash. The ash contained about 33.0 % of water soluble and 66.0 % of water insoluble in organic substances. The ash contained the following positive and negative radicals —

Potassium, Iron, Calcium, Sulphate, Phosphate, and traces of Chloride.

In order to obtain an idea of the constituents present, 25 grammes of the ground seeds were extracted with various solvents successively in a Soxhlet apparatus when the following amounts of extract dried at 100°C were obtained.

✓Ether . . . . .	1.19 g	4.75 %
Petroleum ether . . . . .	0.1 g . . . . .	0.4 %
✓Chloroform . . . . .	0.21 g . . . . .	0.84 %
Ethyl acetate . . . . .	0.12 g . . . . .	0.45 %
✓Alcohol . . . . .	1.2 g . . . . .	4.8 %

The petroleum ether, ether, and chloroform extracts were on examination found to be nothing else than a yellow coloured fixed oil having a characteristic odour.

The alcoholic and ethyl acetate extracts were deep brown in colour and on analysis were found to be mostly mucilaginous matter and a little amount of brown chaffy material and reducing sugars. Nothing definitely crystallisable product could be isolated from the various extracts.

For complete analysis 4 kilogrammes of the powdered seeds were exhaustively extracted with petroleum ether. The extract on complete distillation of the solvent gave 200 grammes of a yellow oil having a peculiar smell of the fruits. The petroleum ether extracted powder was then extracted with rectified spirit till the colour of the extract became light. The solvent was distilled off and made to about 300 c.c. and allowed to stand over night. No solid separated out. Only slimy gelatinous mass settled in the distilling flask. To a few c.c. of the extract distilled water was added but nothing separated out.

The alcoholic extract was then diluted with a little alcohol and an alcoholic solution of lead acetate was added to it. A yellow crystalline lead salt was precipitated. It was filtered and thoroughly washed with alcohol. From the filtrate of the lead salt no second lead salt with basic lead acetate was precipitated. On removing the excess of lead by  $H_2S$  and concentrating the mother liquor nothing except a large amount of reducing sugars and inorganic material could be detected.

The yellow crystalline lead salt on purification was decomposed by  $H_2S$  in alcoholic suspension. The filtrate was evaporated to dryness when a brown solid was obtained. It was then washed with acetone which removed the brown colouring impurities and left a white solid behind. This was very mucilaginous and sticky. It gave green colour with neutral ferric chloride, with sulphuric acid a brown colour was developed and in caustic soda it dissolved to a yellowish red solution. It could not be crystallised by any means. At the most a white amorphous semi-sticky mass could be obtained which on addition of a few drops of water became mucilaginous. This, from all its reactions, was identified to be mucilage. The seeds contain a very large proportion of this mucilage to which the soothing property of the drug is supposed to be due.

#### EXAMINATION OF THE OIL

The crude oil was digested with animal charcoal and Fuller's earth and filtered hot through a hot filtering funnel. The purified oil was freed from last traces of petroleum ether by heating over a water bath and finally in a vacuum desiccator. The oil after purification was of a bright yellow colour and possessed a characteristic pleasant odour of the drug. It does not contain nitrogen or sulphur. It has practically a negligible *laevo* rotation  $[\alpha]^{20}_D = -0.1$ . The fatty acids obtained after saponification of the oil is optically inactive, proving that the rotation in oil is due to the presence of the unsaponifiable matter. It burns with a semi-sooty and

odourless flame. In order to test the drying power of the oil a few drops of it were spread on a clean glass plate and kept at room temperature. After a fortnight the oil became very slightly sticky, proving it to be of the class of semi-drying oils. The physical and chemical constants of the oil are given in Table I

TABLE I

Specific gravity	0.9212 at 22°C
Refractive index	1.4737 at 28°C
Viscosity	7.057 (compared to rape oil)
Solidifying point	-8°C
Acid value	5.166
Saponification value	181.8
Acetyl value	37.7
Unsaponifiable matter	1.8% to 2%.
Hehener's value	91.8
Iodine value	116

Seventy-five grammes of the oil was then saponified with alcoholic potash and the unsaponifiable matter was removed with ether in the usual way. The soap solution was dissolved in excess of water and decomposed with dilute  $H_2SO_4$  in presence of petroleum ether. The petroleum ether fatty acid layer was washed free from traces of sulphuric acid in a separating funnel. The mixture of the fatty acids was next freed from moisture with fused calcium chloride, filtered and petroleum ether was distilled off. Table II gives the constants of the fatty acids separated from the oil.

TABLE II

Specific gravity	0.8618 at 20°C
Refractive index	1.4655 at 28°C
Neutralisation value	188.5
Mean Molecular weight	297.8
Iodine value	122.3

The mixture of the fatty acids were then separated into saturated and unsaturated acids (i) by lead-salt-ether method. (ii) Twitchell's lead-salt-alcohol method. The separation of the saturated and unsaturated acids is more quantitative by the second method as is apparent from the iodine value of the saturated acids. In the experiment with Twitchell's method of separation 20.9 g. of the fatty acids isolated previously was dissolved

in 500 c c of 95% ethyl alcohol. The solution was boiled and to it was added a boiling solution of 250 c c alcohol containing 13gs of lead acetate. The mixture was kept at room temperature (15°C) overnight and the precipitated lead salt was filtered and washed free of lead with alcohol. The precipitate was again dissolved in 200 c c of boiling 95% alcohol containing 1 g of acetic acid and the solution cooled overnight. The precipitate was filtered, purified and decomposed with dilute nitric acid in ethereal solution. The ether solution was washed free of nitric acid, dried and the solid acids were recovered. The mixture of the filtrate of the insoluble salt was decomposed with dilute nitric acid and the liquid acids isolated as before.

Table III gives the percentage of saturated acids as estimated by two methods

TABLE III

	% of Saturated acids	% of Unsaturated acids	Iodine value of saturated acids
(1) Lead-salt-ether method	15.1	84.6	36.7
(2) Lead-salt-alcohol method	12.43	87.57	30.24

#### EXAMINATION OF THE UNSATURATED ACIDS

*Klaidin test for the liquid acids* - 1 g. of the liquid acid was treated with 5 c.c of nitric acid and 0.6 g. of sodium nitrite was added in small portions and was allowed to stand in a cool place. After some time the acid solidified. The product was next pressed on a porous plate and the resultant solid, when crystallised from ether melted at 45-46°C and was identical with elaidic acid.

#### OXIDATION OF UNSATURATED ACIDS WITH POTASSIUM PERMANGANATE

10 gs of the acids were taken in a flask and dissolved in caustic potash and 2% solution of potassium permanganate was added to it in small instalments at room temperature with constant stirring. After the reaction a current of SO<sub>2</sub> was passed through the solution to dissolve the precipitated manganese dioxide. The insoluble white substance was filtered and extracted with ether. The ethereal extract after removal of the

solvent, deposited a crystalline white product which on further purification and crystallisation from alcohol melted at  $131-32^{\circ}\text{C}$  and was identified to be dihydroxy-stearic acid. The formation of this acid proved the presence of oleic acid in the liquid acids. The ether insoluble portion of the oxidation product was extracted with boiling water and the filtrate on cooling deposited crystals which on drying melted at  $164-65^{\circ}\text{C}$  and was proved to be identical to (sativic acid) tetrahydroxy-stearic acid. The formation of this acid proved the presence of linolic acid in the oil. The presence of traces of hexahydroxy-stearic acid was established—proving the presence of traces of linolenic acid in the liquid acids.

The constituents of the unsaturated acids were also quantitatively estimated by means of their bromine addition products as recommended by Jamieson and Baughmann<sup>4</sup>. Accordingly, a known weight of the unsaturated acid was dissolved in 130 c.c of dry ether and was cooled in a freezing mixture to  $-10^{\circ}\text{C}$  and bromine was added drop by drop till it was in excess. The mixture was not allowed to rise more than  $-5^{\circ}\text{C}$  during the addition of bromine. Then the mixture was allowed to stand for 2 hours at  $-10^{\circ}\text{C}$ . After two hours very little precipitate was obtained. This was filtered, washed with dry ether, dried and then weighed. The weight of the hexabromide was 0.038 g from 4.6865 gs. of the unsaturated acids, showing thereby that linolenic acid was present in traces only. The ethereal liquid was then freed from excess of bromine with an aqueous solution of sodium-thiosulphate (hypo) in a separating funnel. The solution was then dried with fused calcium chloride, filtered and the ether distilled off. The residue was dissolved in 150 c.c of dry petroleum ether with boiling and the flask was allowed to remain in the ice-chest overnight. The precipitate of the tetrabromolenolic acid was filtered, washed and dried. The filtrate and washings were concentrated to 60 c.c. and again allowed to stand overnight in the ice-chest. The second crop of precipitate was filtered again and was added to the first and weighed. It melted at  $113-14^{\circ}\text{C}$ . The filtrate was concentrated to 30 c.c and was kept as before but this time no precipitate was formed. Finally the petroleum ether was completely removed and the precipitate weighed and its bromine content estimated. The following table V contains the data of the analysis of the bromo derivatives.

The Iodine value of the mixture of unsaturated acids was found to be 142.5. Since the presence of linolenic acid was shown to be in traces both qualitatively and quantitatively it can be regarded that the unsaturated acids contain only a mixture of oleic and linolic acids for all practical purposes. Thus the proportion of linolic acid and oleic acid



can be calculated from the iodine value by the help of the following equations.—

$$\begin{aligned} X + Y &= 100 \\ 90.07 X + 181.14 Y &= 100 \times I \\ \text{when } X &= \% \text{ of oleic acid} \\ Y &= \% \text{ of linolic acid} \\ \text{and } I &= \text{the iodine value} \\ 90.07 + 181.14 Y &= 100 \times 142.5 \end{aligned}$$

Table IV gives the percentage of oleic and linolic acids calculated from the above equation

TABLE IV

	% in the unsaturated acids	% in the total fatty acids	% in the original oil
Oleic acid ..	43.51	37.85	37.09
Linolic acid	56.49	49.15	48.16

TABLE V

Weight of the unsaturated acids taken	4.6868 gs
Linolenic acid hexabromide insoluble in ether,	0.038 g.
Linolic acid tetrabromide insoluble in petroleum ether	2.9475 gs
Residue (dibromide and tetrabromide)	5.4386 gs.
Bromine content of the residue	45.38 %
Dibromo oleic acid in the residue ..	(58.38) % 3.1662 gs
Tetrabromo linolic acid in the residue	(41.79 %) 2.2725 gs
Total tetrabromo linolic acid	3.2200 gs
Linolic acid equivalent to the tetrabromide .	2.6240 gs or 56.25 %
Oleic acid equivalent to dibromide ..	2.0200 gs or 43.10 %

Table VI gives the percentage of oleic and linolic and linolenic acids in the unsaturated acids calculated from the above data.

TABLE VI

	% in the unsaturated acids.	% in the total fatty acids.	% in the original oil.
Linolenic .	0.286	0.250	0.244
Oleic ..	43.10	37.5	36.75
Linolic , ...	56.25	48.94	47.95

### SATURATED ACIDS

The saturated acids separated by the lead-salt-alcohol method were freed from traces of liquid acids by pressing over porous plate. The acids thus obtained were perfectly solid, yellowish white in colour and melted between 54-56°C. They were dissolved in alcohol and precipitated by diluting with water. Two solid acids separated thereby which on crystallisation from alcohol melted at 61°C and about 65°C respectively. The quantity of the saturated acids obtained was so small that nothing definite could be identified. Utmost that could be done was that from the melting points and by means of some qualitative reactions according to the methods of Kreis and Hafner<sup>5</sup> and Hehner and Mitchell,<sup>6</sup> the presence of palmitic and stearic acids was definitely confirmed. But the quantity of the saturated acids being too small they could not be quantitatively separated.

### EXAMINATION OF THE UN-SAPONIFIABLE MATTER

The unsaponifiable matter obtained by ether extraction of the soap and consequent evaporation of the solvent was of a bright yellowish colour and was obtained in waxy flakes. It was crystallised from alcohol. On repeated crystallisation fine colourless crystalline silky flakes and needles were obtained which melted at 132-133°C. From the reactions it was identified to be phytosterol. The acetyl derivative of it melted at 119-120°C. One combustion of the substance was done (C=83.8%, H=10.7%). The sterol was proved to be Sitosterol, m.p. 133-134°C.  $C_{27}H_{44}O$ ,  $H_2O$  requires C, 84.3%, H, 10.4%. In addition of the sterol there was some bright sticky yellow colouring matter. The quantity was too small for systematic examination.

### SUMMARY

The examination of the oil showed the presence of :—

- (1) Oleic acid, linolic acid 37%, 48% and linolenic acid in traces among unsaturated acids.
- (2) Palmitic and stearic acid among saturated acids (12.5 %)
- (3) Sitosterol in the unsaponifiable matter (1.8 to 2%)

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# CHEMICAL EXAMINATION OF THE KERNELS OF THE SEEDS OF *CÆSALPINIA BONDUCELLA*

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*Cæsalpina bonducella*, or *Katharanj* as it is known in Hindustani and *Nala-karanja* in Bengali, is a plant of the natural order Leguminosæ. This plant has long been well known to Hindu and Mohammedan physicians as having medicinal properties. It is found near the coast in all hot countries. The seeds of the plant are nearly globular in shape varying in size from  $\frac{1}{2}$  to  $\frac{3}{4}$  inch in diameter, they are of a dull grey colour, smooth and very hard. The shell is thick and brittle and contains a yellowish-white kernel having very bitter taste. The root, bark, leaves and the seeds are used in medicine. The seeds are very useful and cheap, anti-periodic, antipyretic and tonic, valuable in all ordinary cases of simple, continued and intermittent fevers. The roasted seeds are given internally in leprosy and have been found useful in some cases of asthma. The seeds are officinal in the Indian Pharmacopœia and useful in malarial fevers. Bonducella oil is emollient and is used as an embrocation to remove freckles from the face, as a cosmetic and also to stop discharges from the ear.

Heckel and Schlagdenhauffen<sup>1</sup> were probably the first to have systematically attempted to work out the chemical constituents of *Cæsalpina bonducella* nuts. They isolated an oil, starch, inorganic salts and

an amorphous non-alkaloidal bitter principle, 'bonducin' to which they gave the formula  $C_{14}H_{15}O_5$ . The authors attributed the physiological properties of the seeds to bonducin. Bacon<sup>3</sup> was next to have isolated the bitter principle, bonducin, which he found to be a mixture of complex resinous bodies. He could not obtain any alkaloid or glucoside from the alcoholic extract of the kernels. Bhaduri<sup>4</sup> claimed to have isolated an alkaloid from the kernels of the seeds and to which he suggested the name 'natin', but he gave little experimental details in support of his findings. Godbole, Paranjpe, and Shrikhande<sup>4</sup> isolated a sulphur containing glucoside from the alcoholic extract of the kernels. Recently Tummin Katti<sup>5</sup> isolated a bitter principle of the character of a complex mixture of resinous bodies. He also found out the fatty acids and sterols contained in the oil and two phytosterolins. Tummin Katti and Puntambekar,<sup>6</sup> in a separate communication, gave the results of their examination of the fatty oil. Thus, it is apparent from the above literature that in spite of repeated attempts of several workers to study the chemical nature of the bitter principle, the problem remained still unsolved. The present work was, therefore, taken up in order to throw some light on the chemical nature of the bitter principle. The oil obtained from the seeds was not analysed in view of the fact that the fatty acids contained in it have been determined. The present examination of the kernels of the seeds of *Cesalpinia bonducella* has proved the presence of a non-crystalline bitter glucoside having a molecular formula  $C_{20}H_{28}O_6$  and melting at 119-120°C, a neutral saponin, starch, sucrose, an amorphous tasteless powder, a starch hydrolysing enzyme and a yellow oil. The bitter principle has been named as 'bonducin' by the present author after Heckel and Schlagdenhauffen who were first workers in this field. Bonducin is optically active, having a dextro rotation of +25.6 in ethyl alcohol. The presence of any alkaloid or sulphur containing glucoside, as claimed by some of the previous workers, could not be substantiated.

#### EXPERIMENTAL

The seeds of *Cesalpinia bonducella* were obtained from the local market. The kernels were found to be 44.3 per cent of the entire seeds.

**Test for alkaloids.** Twenty grammes of the powdered oil-free kernels were tested for the presence of alkaloids, but with negative results.

*Test for enzymes* Fifty grammes of the crushed kernels were freed from oil by continuous percolation of cold petroleum ether. The powder was completely freed from the solvent under diminished pressure at room temperature and was kept in a flask with 200 c.c. of distilled water and few drops of toluene. After two hours a little of the filtrate was found not to reduce Fehling's solution. But after two days a little of the fresh filtrate from the flask produced a heavy precipitate of cuprous oxide on heating with Fehling's solution. This reaction definitely proved the presence of a starch hydrolysing enzyme in the kernels.

*Starch* Ten grammes of the oil-free powder was extracted with hot water. The filtrate developed the characteristic deep blue coloration with iodine solution.

For complete analysis two kilogrammes of the powdered kernels were extracted several times with petroleum ether. The extract on distillation of the solvent gave 418 grammes of a pale yellow oil. The drug was freed from petroleum ether and completely extracted with chloroform. The total chloroform extract was concentrated to a volume of about 200 c.c., when it was obtained as a thick brown liquid. It was left for several days, but nothing separated. To the concentrated chloroform extract was added a large volume of petroleum ether when a flocculent yellowish-white precipitate separated. The addition of petroleum ether was stopped when it was found to be no more effective towards further separation of the substance. When the substance settled at the bottom of the flask, the mother liquor was decanted off. The precipitate was filtered and washed several times with small quantities of petroleum ether. It was obtained as whitish amorphous powder and weighed 11 grammes. It was intensely bitter and melted between 105-114°C. This substance has been named as 'bonducin' and its properties have been described separately. The petroleum ether filtrate gave a further quantity of 60 grammes of the oil. Thus, the total oil obtained amounted to 23.9 per cent of the weight of the kernels.

The drug was freed from chloroform and exhaustively extracted with rectified spirit. The total alcoholic extract was distilled under reduced pressure till it was obtained as a semi-solid pasty mass of a white colour. It was left for about a fortnight in a desiccator over sulphuric acid when small regular crystals appeared at the surface. Some of the crystalline stuff on analysis was found to be pure sucrose. The solid lump was powdered and extracted several times with cold alcohol (about 70 per cent) till the extract was found not to dissolve anything

further The weight of the solid substance, left after cold alcoholic (70 per cent) extraction and on drying was 81 grammes

The filtrate was concentrated to a small volume. It gave no coloration with ferric chloride and did not reduce Fehling's solution Lead acetate solution did not give any precipitate but a flocculent white precipitate was formed on addition of lead subacetate solution. The precipitate was purified and decomposed in alcoholic (80 per cent) suspension with  $H_2S$  The filtrate on drying under reduced pressure gave a fawn-coloured amorphous mass The substance was identified to be a neutral saponin as its aqueous solution responded to the following reactions

- 1 formed a barium salt with barium hydroxide solution ;
- 2 reduced ammoniacal silver nitrate and on prolonged boiling with mercuric chloride solution precipitated calomel;
- 3 produced a blue coloration on addition of a little of the substance to a solution of potassium ferricyanide containing ferric chloride,
- 4 reduced Fehling's solution after being hydrolysed with dilute hydrochloric acid

From the filtrate of the lead salt no other substance could be isolated excepting sucrose, which was present in fair amount

The solid lump, as separated from the original alcoholic extract, was crystallized from boiling alcohol The filtrate on long standing deposited monoclinic prisms It melted at  $171^{\circ}C$ , (mixed melting point with Merck's sucrose was  $171^{\circ}C$ .) and readily reduced Fehling's solution after being hydrolysed with dilute hydrochloric acid It formed an acetylated compound melting at  $67^{\circ}C$  It was optically active, having a dextro rotation of  $+67.3$  in distilled water

[Found: C, 41.9, H, 6.5 per cent,  $C_{12}H_{22}O_{11}$  requires, C, 42.1; H, 6.4 per cent] The substance was therefore sucrose

The amorphous mass as obtained from the chloroform extract was dissolved in minimum quantity of hot chloroform, filtered and precipitated by addition of petroleum ether The solid product thus obtained was extracted with carbon tetrachloride several times. A small portion, in the form of yellowish-white amorphous powder, remained insoluble. This product was tasteless and melted at  $107-109^{\circ}C$ . The following are the combustion results of the substance: C, 56.07 per cent, H, 8.62 per cent The quantity being very small, it could not be studied further. The substance is insoluble in water, but soluble in alcohol. It does not contain nitrogen and sulphur.

The carbon tetrachloride filtrate of the above was concentrated to a small volume and kept for crystallization. After two days a soft solid

layer separated at the top. It was removed and on drying was obtained as an amorphous mass of almost white colour. It melted at 119-120°C and possessed a very persistent bitter taste. This product has been named as 'bonducin'. The substance in carbon tetrachloride solution was recovered on complete evaporation of the solvent. It was a slightly impure specimen of bonducin and melted at 117-119°C.

Bonducin is insoluble in water, but dissolves in acetic acid, acetone, methyl and ethyl alcohols, ethyl acetate, pyridine, chloroform and carbon tetrachloride. Ordinarily it does not reduce Fehling's solution, but readily reduces the same after being hydrolysed with dilute hydrochloric acid. It does not form any precipitate with lead acetate or subacetate, but gives a light yellow precipitate with barium hydroxide, and develops no coloration with neutral ferric chloride. With chloroform, acetic anhydride and concentrated sulphuric acid bonducin develops a purple coloration, which on standing becomes dark brown. It does not contain nitrogen and sulphur. All attempts to get bonducin in a crystalline form were unsuccessful. It dissolves in nitric acid with a cherry-red colour. In sulphuric acid bonducin dissolves with orange colour which turns red and finally dark brown. Bonducin is optically active, having a dextro rotation of +25.6 in ethyl alcohol.

[Found: C, 59.82, 59.95 per cent; H, 7.18, 7.21 per cent, MW, (cryoscopic in phenol) 363, 399, 372;  $C_{10}H_{18}O_8$ , requires, C, 60.60, H, 7.07; MW., 396.]

*Hydrolysis of bonducin* One gramme of bonducin was dissolved in dilute alcohol and refluxed for about an hour with dilute hydrochloric acid. To the brown solution water was added. It was then allowed to evaporate slowly over water bath. On evaporation of alcohol a brown liquid separated at the bottom. It was allowed to stand overnight. The solid mass, which became brittle, was broken to powder and filtered. In the filtrate the presence of glucose was confirmed by preparing phenyl-glucosazone m.p., 205°C. The solid, which was in all probability the glucogenin, was dissolved in dilute alcohol and separated as before. It was obtained as a pale yellow amorphous mass melting at 127-128°C. It had no taste. This substance dissolved in concentrated nitric and sulphuric acids forming deep red solutions. The latter solution became dark brown after some time.

The author wishes to express his indebtedness to the "Lady Tata Memorial Trust," Bombay, for a scholarship which enabled him to take up this investigation.

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# ORIGIN OF COMBINED NITROGEN IN THE ATMOSPHERE THE ANALYSIS OF TROPICAL RAIN AND ITS IMPORTANCE IN AGRICULTURE

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It is well known that nitrogenous compounds are of great value to the plants and that is why, ammonium salts, urica, etc, are used as artificial manures. Most of the nitrogen required by the plants is obtained from the soil where it is present in the form of nitrates, ammonium salts and other complex nitrogenous compounds. The complex nitrogenous compounds should first be converted into ammonia and then into nitrites and nitrates before they can be absorbed by the plants, through the processes of ammonification and nitrification.

It is generally believed that a good quantity of nitrites and nitrates falls on the surface of earth with rain water. That this nitrogen washed down by the rain constitutes an important source of soil nitrogen has been a matter of great controversy since the time of Liebig. As a result of their extensive researches Russel and Richards<sup>1</sup> and Miller<sup>2</sup> have come to the conclusion that nitrogen washed down with the rain is of very little significance to agriculture. The nitric nitrogen in the atmosphere is present either as the oxides of nitrogen or ammonium nitrite and nitrate.

Regarding the origin of nitric nitrogen present in the atmosphere it is generally believed that they are produced there due to the occurrence of thunderstorms, but the observations of Wilson<sup>3</sup> and Trieschmann<sup>4</sup> appear to show that the amount of nitric nitrogen present in the atmosphere is not at all affected by the incidence of thunderstorms<sup>1</sup> and other electrical disturbances. It has been observed by many workers that summer rains contain more nitrogen than that falling in winter, and that wind, electrical discharges and other meteorological conditions appear to have but little effect on the quantity of nitric nitrogen present in rain water (cf. Wilson and Trieschmann.)

In publications from these laboratories Dhar and collaborators<sup>6</sup> have emphasised that nitrification in the soil is partly due to the photosensitised oxidation of ammonia and its compounds on the surface of soil under the action of sunlight. It is expected that a similar process may be taking place in the atmosphere, i.e., nitric nitrogen which is detected in rain water may be produced due to the oxidation of ammonia under the action of sunlight. On this hypothesis it is expected that the ratio of ammoniacal to nitric nitrogen in the rain water available in tropical countries should be much greater than that obtained in the rain water collected in temperate and frigid climates. In order to test this point a systematic analysis of rain water falling at Allahabad has been undertaken by the author as no satisfactory data on this question are available.

### EXPERIMENTAL

The procedure adopted in the analysis of rain water was as follows —

The rain water was collected in a Jena bottle which was kept below a glass funnel which acted as a receiver of water. The bottle was protected from dust coming in by means of a tin shade. This also served to avoid the entrance of water into the bottle other than that falling in the funnel. A separate rain gauge was also fitted to measure the amount of rainfall. About 200 cc. of the freshly collected rain water were taken in a distilling flask and evaporated to about 30 cc in the presence of caustic potash so that ammonia present in rain water both as free and combined state was removed. Nitric nitrogen of rain water now present as potassium salts was reduced by Devarda's alloy. Ammonia obtained by reduction was caught in two small flasks containing dilute sulphuric acid. The amount of ammonia so obtained was estimated by the colorimetric method using Nessler's reagent. From the amount of ammonia the amount of nitric nitrogen could be easily calculated. The amount of nitrites present in rain water was estimated colorimetrically using the naphthalamine sulphanilic acid test. The amount of ammonia present in the free and combined can be easily estimated by the colorimetric method taking the original rain water and comparing it with a standard ammonium chloride solution. That ammonia obtained by reduction was not due to the impurities present in the alloy or the alkali a blank experiment, using the same amount of alkali and the alloy as used in the analysis of rain water was always performed with conductivity water and the amount of ammonia so obtained, if at all, was always deducted from the actual

amount available after reduction. In order that all the nitrites and nitrates present in rain water be completely reduced, reduction should be carried on twice and the total time required for reduction is eight hours, since it is very tedious to reduce nitrates when they are present in small quantities. In the following table some of the results are summarised.—

TABLE I

Date	Ammoniacal N in mgms per litre.	Nitric N in mgms per litre	Ratio of to amino N
21st August, 1932	0.20	0.50	2.5
2nd September, 1932	1.02	2.56	2.5
3rd Do 1932	0.17	0.70	4.1
3rd Do 1932	0.16	0.70	4.4
4th Do. 1932	0.24	0.70	3.1
5th Do 1932	0.17	0.61	3.6
6th Do 1932	0.11	0.45	4.1
6th Do 1932	0.10	0.43	4.3
16th Do 1932 (I)	0.60	1.65	2.7
16th Do 1932 (II)	0.28	0.88	3.1
16th Do 1932 (III)	0.24	0.87	3.6
23rd October, 1932 (I)	0.37	0.81	2.2
23rd Do. 1932 (II)	0.36	0.86	2.4

In order to test whether the amount of nitric nitrogen present in rain water has some relation with the incidence of thunderstorms the following results were obtained. From these observations it will be seen that the incidence of thunderstorms and electric lightning and discharge has not much effect on the amount of nitric nitrogen present in the atmosphere.

TABLE II

Date	Ammoniacal N in mgms per litre	Nitric N in mgms per litre	Ratio Nitric N/Ammon. N	Whether thunderstorm occurred or not
13th January, 1933	1 456	1 232	0 85	Occasional thunderstorm
15th Do 1933	0 612	0 434	0 72	Thunderstorm
22nd Do 1933	0 436	0 280	0 64	Do
24th Do 1933	0 596	0 336	0 6	Do
12th April, 1933	0 684	0 852	1 26	No thunderstorm.
14th Do 1933	0 804	1 325	1 64	Do
22nd April, 1933 I	0 840	1 580	1 9	No thunderstorm but lightning once or twice
22nd April, 1933 II	0 404	0 748	1 86	Not very frequent
Mean of Table I & II	0 469	0 881	1 9	

In the following table are given the results obtained in different countries on the amounts of ammoniacal nitric and total nitrogen available in the rain water —

TABLE III

*Non-industrial places (Tropics)*

Place	Latitude	Ammoniacal N in lbs per acre	Nitric N in lbs. per acre	Ratio Nitric N/Ammon. N	Total N per acre in lbs
British Guinea	5 0 N	1 006	2 541	2 5	3 547
Venezuela	10 30 N	..	7 87	..	..
Barbados	13 10 N	1 009	2 443	2 42	3 452
Reunion	21 0 S	..	9 437	..	..
Allahabad	25 28 N	3 065	5 734	1 9	8 799
Mean		1 693	5 605	2 26	5 266

TABLE IV  
Non-industrial places (Temperate)

Place	Latitude	Ammonia- cal N in lbs per acre.	Nitric N in lbs per acre.	Ratio Nitric N Ammo N	Total N received per acre
Geneva (N Y)		7.97	0.96	0.12	8.93
Délira Dun	30 19 N	2.037	1.368	0.67	3.405
Sylhet		4.533	3.757	0.83	8.29
Kokstad	30 34 S	1.702	1.021	0.6	2.723
Mississippi	33 S				3.636
Grahamsyown	33 19 S	1.443	1.16	0.804	2.603
Kansas	38 N	2.63	1.06	0.4	3.69
New Zealand coast	40 S	0.6	0.8	1.33	1.4
Mt Vernon	40 26 N	2.64	1.755	0.66	1.395
Alsace	48 3 N		0.521		
Rothamsted	51 49 N	2.64	1.33	0.50	3.97
Iceland	64 40 N	0.802	0.263	0.328	1.965
Hebrides	56 50 N	0.313	0.289	0.93	0.600
Ottawa	59 3 N	2.99	1.755	0.59	2.745
Mean		1.436	1.02	0.72	2.686

TABLE V  
Industrial places (Tropics)

Place	Latitude.	Ammonia- cal N in lbs. per acre	Nitric N in lbs. per acre	Ratio N A. N	Total nit- rogen re- ceived per acre.
Cawnpore	26 58 N	2.482	0.768	0.31	3.25
Pretoria	25 25 S	6.587	1.083	0.16	7.677
Mean		4.534	0.925	0.235	5.46
<i>Temperate</i>					
Cedar	32°22 S	7.088	1.321	0.16	8.409
Utah (U. S. A.)	39 30 N	5.06	0.356	0.07	5.416
Paris	48 51 N	..	...	.	8.93
Gembloux	50°33 N				9.2
Groningen	51°57 N	4.0	1.2	0.3	5.2
Mean	...	5.382	0.959	0.179	7.431

Thus the ratio  $N/A\ N$  is greater for tropical than for the non-tropical countries, independent of industries, even.

## DISCUSSION

From an examination of the results obtained in the analysis of rain water in tropical countries it will be clear that the ratio of nitric to ammoniacal nitrogen is greater than the corresponding ratio obtained in the temperate and frigid climates. This ratio is higher for the tropical countries whether the locality be industrial or non-industrial. What is the reason of this higher value which is found to be quite coincident for all the countries whose data are available? Moreover, it is also observed that the total nitrogen falling with the rain water is higher in the tropical than in the non-tropical countries.

*Sources of Ammonia in Rain Water.*—As a result of their systematic researches on the analysis of rain water, Miller, Russel and Richards conclude that ammonia obtained in rain water is derived from three sources, the sea, the soil and the atmospheric pollution. A critical examination of the results obtained in different countries on the analysis of rain water will show that the highest value of ammonia are obtained during summer, quite independent of the location of industries in the particular area and also of the total amount of rainfall. The amount of ammonia received by an acre of soil is also greater in the tropical than in the temperate and frigid climates, industrial places being exceptions. The first source of ammonia present in rain water, *i.e.*, the sea seems to be of little significance. If the sea were the source of ammonia present in rain water, it will be necessary that the total amount of ammonia obtained during the year should be dependent on the total amount of rainfall, and also that the amount of ammonia present in the different fractions of the same rainfall should be practically the same. Contrary to this has been the experience of the author and other workers. The amount of ammonia present in the first fraction is greatest and goes on continuously decreasing as the rain is falling (cf. Table I and II). Moreover, the heavier the shower the greater is the proportion of ammonia washed down in the first collection. In an actual experiment which was carried on with a heavy rainfall (1.2") the last fraction contained practically no ammonia. If ammonia present in rain water was to come from the sea along with the monsoon it must have been present practically to the same extent during the whole of the rainfall or at least the last fractions must have contained some ammonia. In the face of these facts there remains very little chance for the ammonia present in the rain water to come from the sea.

The origin of the ammonia present in the atmosphere must be found in the soil or from the burning of coal and the decomposition of the

nitrogenous matter on the surface of the soil. It is well known that the atmosphere of industrial towns is richer in ammonia than that of the rural districts. The reason of this large amount of ammonia is the huge consumption of coal in industrial centres which sets free large amounts of ammonia into the atmosphere. In rural areas, however, the major part of ammonia present in the atmosphere must be derived from the soil.

In publication from these laboratories Dhar and collaborators have shown that not only nitrification but also ammonification is accelerated by sunlight. In tropical countries, the surface of the earth receives more sunlight than in temperate and cold countries and naturally there should be more ammonification in the tropics. A part of the ammonia escapes into the air and this addition of ammonia to the atmosphere appears to be more important in tropical than in non-tropical countries, because the soil in tropical climates attains a much higher temperature than in the temperate and frigid regions. Experiments have been carried on with urea solutions mixed with soil and it has been observed that there is more ammonia formed from urea in sunlight than in the dark, and an appreciable amount of ammonia formed from urea escapes into the air. In this connection the following remarks of Miller (*cf* Chem Soc Annual, Rep. 1913, pp 212) will be worthy of note. "We have evidence that the fairly heavy soil at Rothamsted loses ammonia for some weeks after the application of ammonium salts and it is possible that some soils are more or less continuously giving into the air small portions of the ammonia produced from organic residues. Some soils may be expected to lose more ammonia than is returned in the rain, while others may gain in this manner more than they lose."

Consequently the atmosphere in tropical countries is richer in ammonia than in non-tropical centres free from large industries, that is why the tropical rain contains more ammonia than the rain falling in temperate and frigid regions. Thus it is evident that ammoniacal nitrogen present in the atmosphere and rain water is mainly derived from the soil and the decomposition of organic matter. It seems that the monsoon itself if at all contains very little ammonia. The results obtained so far are more in accordance with the fact that ammonia in the rain is washed from the atmosphere and does not appear to come from the sea.

*Origin of Nitric and Nitrous Nitrogen in the Atmosphere*—The nitrates and nitrites present in rain water are derived from the nitric nitrogen occurring in the atmosphere. The nitric nitrogen present

in the atmosphere exists either as the oxides of nitrogen or as ammonium nitrate and nitrite. These are washed down to the soil by the rain and form an important source of nitrogenous compounds for the nutrition of plant. The origin of this nitric nitrogen has not yet been satisfactorily explained. It was believed that the oxides of nitrogen are produced due to the occurrence of electric discharges in the upper atmosphere. It is well known that the incidence of thunderstorms is not very frequent. If the presence of the oxides of nitrogen is to be ascribed to thunderstorms, they will be washed down to the earth by the rain which follows thunderstorms and no oxides of nitrogen should be present in the atmosphere on ordinary days. But that is not the case, the amount of nitric nitrogen present in the air on ordinary days is practically the same as that present on days when thunderstorms occur (*cf* Moore, *Biochemistry*, p 72). No relation has yet been established between the variation of the nitric nitrogen present in the atmosphere and the incidence of thunderstorms.

The results summarised in Table II, clearly show that the amount and the ratio of nitric to ammoniacal nitrogen is quite independent of the occurrence of thunderstorms. A similar observation has been made by Das, Sen and Pal<sup>6</sup>. This fact is also supported by the observations of Russel and Richards, Miller, Wilson, Trieschmann, all of whom have found no relation between the occurrence of thunderstorms and electric lightning and the amount of nitric nitrogen present in the atmosphere.

It has been stated by Moore,<sup>7</sup> that sunlight causes a slight union of nitrogen and oxygen, resulting in the formation of the oxides of nitrogen. Dhar and Sanyal,<sup>8</sup> Atma Ram and Dhar<sup>9</sup> have observed the formation of the traces of nitrites when air freed from impurities is bubbled through conductivity water exposed to radiations from a mercury vapour lamp or sunlight. The photo-chemical combination of oxygen and nitrogen seems to contribute a part of the total nitric nitrogen present in the atmosphere. We have recently advanced the view, that the important source of nitric nitrogen in the atmosphere, is the photo-oxidation of ammonia by air in presence of sunlight. Thus the author is of the opinion that the nitric nitrogen present in the atmosphere comes from two sources.

1. The combination of nitrogen and oxygen present in the air in presence of the ultra-violet light from the sun

2. The photo-chemical oxidation of ammonia to nitrites and nitrates, by the oxygen of the atmosphere under the action of ultra-violet light from the sun. Whether the oxidation of ammonia present in the atmos-



phere is brought about through *ozone* formation or by direct activation of the oxygen molecules, is a question which I am yet incapable to answer.

Since the intensity of sunlight and the length of the day is greater in the tropical than in non-tropical countries, it will be expected from the photo-chemical view advanced here that the ratio of nitric to ammoniacal nitrogen must be higher in the tropical than in non-tropical countries. This fact is abundantly clear from the results obtained by the author and those of other workers summarised in the tables. It also demands that nitric nitrogen content of the atmosphere should be greater in the tropical countries than in non-tropical ones. This fact is supported by the observations of Russel and Richards and several others, but they have attributed it to the greater likelihood of the incidence of thunderstorms in tropical countries a fact which has already been ruled out.

Apart from the above considerations, the following observations support the photo-chemical theory of the origin of nitric nitrogen present in the atmosphere.

1. The amount of nitrous and nitric nitrogen present in the atmosphere varies with the season. Since the amount of the solar energy falling on a particular area varies with the season it follows from the explanation advanced here that there should be a corresponding variation in the amount of nitric nitrogen in the atmosphere. This fact is clearly borne out by the results of the author and those of Bineau on the analysis of rain water, who recorded the following results in France:—

Season	Amount of nitric nitrogen per litre of rain in m. grams
Winter	0.30
Spring	1.00
Summer	2.00
Autumn	1.00

In this connection it will be interesting to note that Moore has found an important relation between the solar activity and the amount of nitric nitrogen present in the atmosphere and states that there is a direct proportionality between them. The nitric nitrogen is at a maximum during summer and minimum during winter.

2. The proportion of nitric nitrogen in the atmosphere varies with the altitude. Hayhurst and Pring have observed that the proportion of nitric nitrogen is greater at higher altitudes and goes on

decreasing as we descend This is expected from the photochemical view, because the proportion of ultra-violet light received from the sun is greater at high than at low altitudes, since at lower altitudes most of the radiations of short wavelengths are absorbed by ozone and formaldehyde present in the upper atmosphere.

*Total Nitrogen falling with the Rain Water and its Importance in Agriculture.*—Moreover, from an examination of the results recorded in table it will be seen that not only the ratio of nitric to ammoniacal nitrogen present in the atmosphere, but also the total amount of nitrogen falling with the rain of tropical countries is greater than that falling in the temperate and frigid climates This increased amount of nitrogen which is available in the rain water of tropical countries may be ascribed to the following reasons :—

- 1 Combination of nitrogen and oxygen present in the air under the action of short wave radiations from the sun

2. Increased ammonification of the nitrogenous substance present in the soil due to light absorption and the consequent increased evaporation of ammonia from the soil on account of the high temperature attained by the tropical soil in summer, which precedes the rainy season

In India, the application of artificial manures to the soil is not very common and hence in the majority of cases the crops have to depend for their nitrogen requirements on the soil which is hardly manured artificially As far as the utilization of combined nitrogen to the soil is concerned, the Indian farmer is supposed to be the most economic It has been reported that the average yield of wheat crop in India is fairly comparable with those raised in most of the advanced countries where the soil is abundantly fed with artificial manures This is due to several reasons, the important one being the comparatively larger amount of total nitrogen naturally supplied to the soil through rainfall.

It is well known that in the majority of cases nitrogen is assimilated by the plants in the form of nitrates,  $\text{NO}_3$ , in the nitric condition In rain water of tropical countries most of the nitrogen is present in the form of nitrates and thus it can serve as a ready-made food for the plants without the intervention of any process, such as nitrification, etc. Thus it will be seen that in this respect also, tropical agriculture is benefited by rain water to a greater extent than that in cold climates, since the constituents of tropical rain contain greater percentage of directly assimilable nitrogen than that falling in temperate and frigid regions.

The author takes this opportunity of expressing his gratitude to Prof. N R Dhar for the keen interest that he has taken in this investigation.

### SUMMARY

1. Rain water falling at Allahabad (Tropical region) contains 0.469 mg of ammoniacal and 0.881 mg of nitric nitrogen per litre of the freshly collected rain water

2 The ratio of nitric to ammoniacal nitrogen is 1.9

3 The chief source of ammoniacal nitrogen present in rain water seem to be the soil and the decomposition of organic matter on the surface of the soil and very little of it seems to come from the sea along with the monsoon

4 The high ratio of nitric to ammoniacal nitrogen appears to be due to the increased photo-oxidation of the ammonia present in the atmosphere and the photo-chemical combination of oxygen and nitrogen under the action of ultra-violet rays coming from the sun

5 The amount of ammonia present in rain water of industrial places is high and seems to depend on the coal consumption and decomposition of organic matter

6. From an examination of the results on the analysis of rain water in different countries it seems that the ratio of nitric to ammoniacal nitrogen is greater in tropical than in non-tropical ones

7 There is a seasonal variation in the amount of nitric nitrogen present in the atmosphere the maximum being in the summer and minimum in winter

8. The origin of nitric nitrogen has been explained from the photo-chemical point of view The amount of nitric nitrogen present in the atmosphere seems to have no connection with the incidence of thunderstorms

9. The amount of total nitrogen falling with the rain water on the surface of the earth is greater in tropical than in non-tropical ones This appears to be due to the increased photo-chemical combination of nitrogen and oxygen and increased ammonification in the soil in the presence of sunlight and the consequent escape of ammonia into the atmosphere.

10 The tropical agriculture is more benefited by rain water than the non-tropical one.

11. The real factor governing the fertility of the soil seems to be the C. N. ratio in the soil and not the total supply of the nitrogenous fertilisers.

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# SYNTHETIC ALKALOIDS DERIVED FROM NARCOTINE

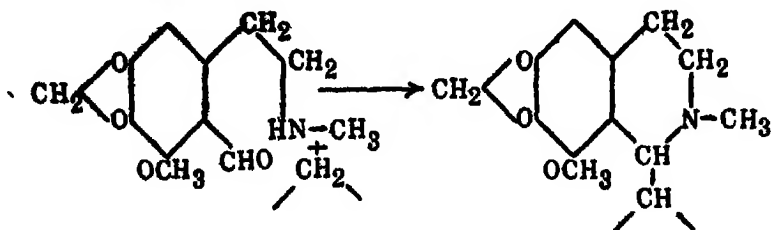
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Narcotine is one of the most important constituents of opium being present in that substance to the extent of more than 5 per cent. Amongst the opium alkaloids, it is well known that those belonging to the isoquinoline group are far less physiologically active than those belonging to the morphine group which contain a phenanthrene nucleus. But unfortunately narcotine belongs to the isoquinoline group and hence it is inert physiologically. Therefore it has not found any use in medicine and neither it has any technical or industrial importance. In opium factories vast stocks of this often accumulate for which there is no useful outlet. The present investigation was, therefore, undertaken in order to find out some suitable means of its utilisation.

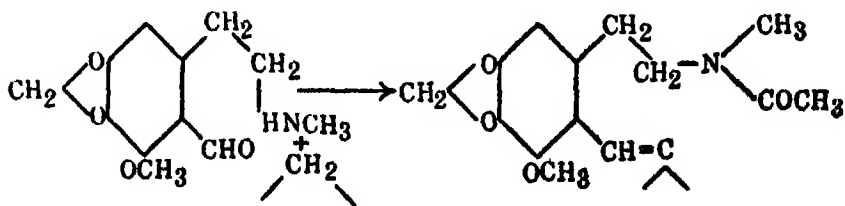
Although narcotine is practically inert chemically, yet on oxidation with nitric acid it yields a substance—cotarnine, by disruption of the isoquinoline nucleus. Cotarnine contains an aldehyde group and a secondary nitrogen atom in juxta position to one another and on that account it is very reactive and condenses with a wide variety of other substances. The usual methods of its condensation consist in ring closure between these reactive groups whenever a substance containing a labile hydrogen atom is allowed to condense with cotarnine, in accordance with the following scheme



The condensing agent usually used for this purpose is invariably sodium ethoxide, which eliminates a molecule of water with great facility in

most of the cases and closed-ring compounds are formed. Various authors like Foulds and Perkin<sup>1</sup>, Ahluwalia, Kochhar and Ray<sup>2</sup>, Ahluwalia, Narang and Ray<sup>3</sup> have prepared a number of condensation products from cotarnine in this way by interaction with such reactive materials as p-nitrotoluene,  $\alpha$ -methylindole, resorcinol, pyrogallol, phloroglucinol, phenylmethyl-pyrazolone, etc. But unfortunately most of these substances have no pronounced physiological action, for in course of production of these compounds, the isoquinoline nucleus is reformed, and this is responsible for the physiological inactivity of these substances in the same way as for narcotine itself.

In view of the facts given above, the present authors thought it useless to try to prepare more compounds from cotarnine by condensation in presence of sodium ethoxide which would invariably lead to the formation of the physiologically inactive isoquinoline nucleus. Therefore their attention was drawn towards other methods of condensation by different condensing agents. On account of the great physiological activity of unsaturated compounds like cinchonine, quinine, safrol, carvone, crotonaldehyde, neurine, muscarine, etc., it was thought that if the oxygen atom of the aldehyde group of cotarnine could be made to condense with reactive methylene compounds without interference from the secondary nitrogen atom, then unsaturated compounds would be formed, which would probably be more physiologically reactive. This expectation has been realised, and it has been found that acetic anhydride is a suitable condensing agent for this purpose bringing about the condensation in accordance with the following scheme:



The following compounds have been condensed with cotarnine in presence of acetic anhydride and the corresponding condensation product obtained: phenylacetic acid, ethylmalonate, desoxybenzoin, benzylcyanide, oxaloacetic ester, acetone-dicarboxylic ester, succino-succinic ester, thiohydantoin, barbituric acid, dimethylhydroresorcin, acetophenone, hippuric acid, camphor, cyanacetic ester, acetoacetic ester, fluorene, acetylacetone, benzoylacetone, 2:4-dinitrotoluene, benzylidene-acetone,

piperonal-acetone, cinnamylidene-acetone and furylidene-acetone. The compounds are described in the experimental portion of the paper.

Cotarnine is a tautomeric substance and can exist either in the carbinol or ammonium form depending on the nature of the medium. This has been actually shown by the spectroscopic investigations of Dobbie, Lauder and Tinker<sup>4</sup> that the structure of cotarnine varies with the nature of the solvent in which it is dissolved. In presence of alkalis it invariably exists in the carbinol form and to this the solubility of cotarnine in alkalis depends. And it is on the basis of the carbinol form that the previous workers have established their conclusions that only ring closure with formation of isoquinoline derivatives took place in their condensation products since the condensing agent used by them was sodium ethoxide which is alkaline.

Now in the presence of acidic medium carbinol form ceases to exist only the ammonium form being stable. The solubility of cotarnine in acids, even in such weak acids as acetic acid and the formation of stable salts can only be due to the production of derivatives of the ammonium form, and the formation of apophyllinic acid from cotarnine by oxidation with nitric acid can only be explained on this assumption.

In order to evolve a structure for the condensation products described in this paper which have been carried on in presence of acetic anhydride, *etc.*, in an acidic medium, it can be easily seen that only two kinds of formations are possible, namely, one of the ammonium form and the other of the open-chain form. With regard to the former it may be said that condensation of cotarnine with reactive methylene compounds in the ammonium form is highly improbable, since in presence of the acidic medium cotarnine will instantly form salts, and hence under these circumstances no condensation can take place. Hence the only other possibility to explain the condensation reactions is to take into account the open-chain formula of cotarnine. Here in presence of acetic anhydride the secondary base gets instantly acetylated, so that the imino group cannot take any part in the condensation reactions in which only the aldehyde group reacts as in Claisen's and Knœvanegal's reactions. Consequently an ethyleneic linkage is formed which explains the unsaturated properties of the condensation products.

The products obtained from thiohydantoin and barbituric acid were found to be di-acetylated. This can be explained by taking into account the enolisation of the condensation product and its subsequent acetylation in presence of the acetic anhydride.

Condensation products with picoline, lutidine, collidine and quinaldine were found to have the same melting point (197°). On careful examination these were found to be one and the same thing and identical with the acetyl derivative of cotarnine itself in the carbinol form and which can be easily prepared from cotarnine by the action of acetic anhydride and pyridine. Hence it can be easily seen that cotarnine does not condense with the compounds mentioned above, probably due to their alkaline nature which stabilises the carbinol form. On treatment of cotarnine with acetic anhydride alone, i.e., without the presence of pyridine, an altogether different substance was obtained, which melted at 124°. This substance was found to be insoluble in mineral acids and therefore could not be cotarnine itself. On examination it was found to contain a free aldehyde group and it must be therefore the acetyl derivative of cotarnine in the open-chain form.

The condensation products described in this paper give interesting colour reactions with concentrated sulphuric acid and most of the alkaloid reagents. The physiological action that has been examined in brief in only a few of the cases points to their being much more potent in this respect than narcotine itself. Detailed physiological and pharmacological actions of these substances are in course of investigation.

### EXPERIMENTAL

The following method gave the best yield of cotarnine in a pure form. Concentrated nitric acid (S.G. 1.42, 47 c.c.) was diluted with water (160 c.c.) and heated in a water bath to 50-55°. To this finely powdered narcotine (20 g.) was added, small quantities at a time with vigorous stirring. The temperature was maintained at 50-55° throughout the process. After all the narcotine was added, the mixture was kept overnight and filtered from small quantities of oily impurities. The filtrate was then strongly cooled with ice and salt and neutralised with concentrated caustic soda solution. The precipitated cotarnine was filtered off, washed with icecold water, dried and crystallised from benzene. M.P. 132°, yield, 13.6 grams.

*Anhydro-N-acetylcotarnine-hippuric acid.*—A mixture of cotarnine (237 g.), hippuric acid (179 g.) and acetic anhydride (20 c.c.) was heated under reflux for one hour and then poured into water. The precipitated reddish brown sticky mass was dissolved in dilute sodium hydroxide, filtered, and the filtrate treated with dilute hydrochloric acid. A pale yellow precipitate was formed which was collected, washed with water,



dried and crystallised from dilute alcohol in yellowish white glistening needles melting at 235°. The substance is very bitter and gives colour reactions with all the alkaloid reagents. A few examples are given below.

**Concentrated sulphuric acid**—The substance dissolves in the cold to an orange coloured solution, which on warming deepens and finally becomes dark brown.

**Concentrated hydrochloric acid**—Dissolves to a colourless solution, but no deepening of the colour on warming.

**Iodine-potassium iodide**—Light brown curdy precipitate.

**Meyer's reagent**—White curdy precipitate which becomes light yellow on standing.

**Dragendorff's reagent**—Dark brown curdy precipitate.

**Phosphotungstic acid**—Flesh-coloured flocculent precipitate.

**Phosphomolybdic acid**—Dirty yellow flocculent precipitate.

**Fröed's reagent**—Orange-red coloration.

**Mandelin's reagent**—Reddish-violet coloration.

Condensations of cotarnine with other reactive substances were carried on in a manner exactly similar to the above. For the sake of abbreviation the properties of these substances are given in tabular forms at the end of the paper. Table No 1 gives the names, formulæ and general properties of these substances, while table No 2 gives the colour reactions with alkaloid reagents.

The physiological properties of these substances which are expected to be very interesting in view of their structure, are in course of investigation. All these substances are unsaturated and they readily decolorise potassium permanganate solution and bromine in chloroform. The deacetylated products have not yet been obtained in a state of purity.

TABLE I  
(A = anhydro-N'-acetyl-cotarnine)

No	Name	Formula	Appearance	M P	Nitrogen %	
					Found	Calculated
1	A-hippuric acid	$C_{13}H_{14}O_7N_2$	Yellowish-white prisms	245°	6.59	6.36
2	A-cauphor	$C_{24}H_{31}O_5N$	Pale pink needles	188°	3.62	3.39
3	A-phenylacetic acid	$C_{22}H_{23}O_6N$	Brownish-white needles	193°	3.81	3.52
4	A-benzylcyanide	$C_{22}H_{22}O_4N_2$	Yellowish-white needles	196°	7.85	7.40
5	A-ethylcyanacetate	$C_{19}H_{22}O_6N_2$	Light orange prisms	95°	7.81	7.48
6	A-ethylmalonate	$C_{21}H_{27}O_8N$	Pale yellow prisms	195°	3.54	3.32
7	A-oxalacetic ester	$C_{22}H_{27}O_9N$	Do	185°	3.38	3.12
8	A-acetoacetic ester	$C_{20}H_{25}O_7N$	Greenish-yellow prisms	192°	3.96	3.58
9	A-acetonedicarboxylic ester	$C_{27}H_{44}O_{13}N_2$	Bright yellow prisms	173°	4.10	3.86
10	A-ethyl-succinosuccinate	$C_{46}H_{46}O_{14}N_2$	Yellowish-white plates	189°	3.84	3.59
11	A-thiohydantoin-acetate	$C_{19}H_{21}O_6SN_3$	Bright yellow needles	227°	10.31	10.62
12	A-malonylurea-acetate	$C_{30}H_{31}O_8N_3$	Brick-red prisms	185°	9.98	9.74
13	A-deoxybenzoin	$C_{28}H_{27}O_5N$	Golden-yellow needles	169°	3.23	3.06

14	A-fluorene	C <sub>27</sub> H <sub>25</sub> O <sub>4</sub> N	Colourless plates	201°	342	328
15	A-acetylacetone	C <sub>19</sub> H <sub>23</sub> O <sub>6</sub> N	Pale yellow prisms	193°	401	387
16	A-benzoylacetone	C <sub>24</sub> H <sub>25</sub> O <sub>6</sub> N	Bright yellow needles	199°	342	331
17	A-dimethylhydrosorcin	C <sub>22</sub> H <sub>27</sub> O <sub>6</sub> N	Do	187°	372	349
18	A-phthalide	C <sub>22</sub> H <sub>21</sub> O <sub>6</sub> N	Colourless needles	196°	355	354
19	A-acetophenone	C <sub>22</sub> H <sub>23</sub> O <sub>6</sub> N	Light brown needles	183°	384	367
20	A-2 4-dinitrotoluene	C <sub>21</sub> H <sub>21</sub> O <sub>8</sub> N <sub>3</sub>	Yellowish white needles	155°	972	948
21	A-benzylidenacetone	C <sub>24</sub> H <sub>25</sub> O <sub>6</sub> N	Greenish-yellow prisms	203°	365	344
22	A-mesityloxide	C <sub>20</sub> H <sub>25</sub> O <sub>5</sub> N	Straw-yellow prisms	194°	412	390
23	A-cinnamylidenacetone	C <sub>26</sub> H <sub>27</sub> O <sub>6</sub> N	Yellowish-white prisms	190°	335	323
24	A-piperonalacetone	C <sub>25</sub> H <sub>25</sub> O <sub>7</sub> N	Greenish-yellow needles	178°	326	310
25	A-furylidenacetone	C <sub>22</sub> H <sub>23</sub> O <sub>6</sub> N	Dull yellow needles	197°	366	352

TABLE II

Meyer's reagent	Iodine-KI	Dragendorf's reagent	Phospho-tungstic acid	Phospho-molybdic acid	Mandeline's reagent	Fröde's reagent
1 White curdy ppt.	Light brown ppt.	Dark brown curdy ppt.	Flesh coloured ppt.	Dirty yellow ppt.	Reddish violet colour	Orange red colour
2 Do	Brown ppt.	Do	Yellow ppt.	Pale yellow ppt.	Dark red colour	Reddish brown colour
3 Pale yellow ppt.	Do.	Do	Pale yellow ppt.	Dirty yellow ppt.	Do.	Dark brown colour
4 White curdy ppt.	Do	Do	Flesh coloured ppt.	Pale yellow ppt.	Dirty violet colour	Do
5 Light yellow ppt.	Light brown ppt.	Do	Yellow flocculent ppt.	Greenish yellow ppt.	Violet red colour	Greenish brown colour
6 White curdy ppt.	Brown ppt.	Do	Do.	Pale yellow ppt.	Blue violet colour	Do
7 Do.	Do	Light brown ppt.	Green yellow ppt.	Greenish brown ppt.	Light green colour	Do
8 Light yellow ppt.	Do	Do	Pale yellow ppt.	Dirty brown ppt.	Bluish green colour	Bluish red colour
9 Do.	Light brown ppt.	Do.	Flesh coloured ppt.	Pale yellow ppt.	Blue colour	Do
10 White ppt.	Dark brown ppt.	Dark brown ppt.	Do	Yellow brown ppt.	Light green colour	Greenish brown colour

11	Yellow ppt	Do.	Do	Yellow ppt.	Pale yellow ppt.	Do	Do
12	White "	Light brown ppt.	Do	Flesh coloured ppt.	Dirty yellow ppt.	Brownish blue colour	Do
13	Yellow "	Do	Do	Yellow ppt.	Do	Do	Do
14	Pale yellow ppt.	Do	Light brown ppt.	White ppt.	Pale yellow ppt.	Light green colour	Do
15	Light yellow ppt.	Dark brown ppt.	Brown curdy ppt.	Pale yellow ppt.	Dirty yellow ppt.	Greenish yellow colour	Bluish brown colour
16	Do.	Do	Do	Do	Greenish yellow ppt.	Do.	Do
17	Do	Light brown ppt.	Do	Flesh coloured ppt.	Dirty yellow ppt.	Dark green colour	Do
18	White ppt.	Dark brown "	Do.	Do	Light yellow ppt.	Emerald green colour	Bluish green colour
19	Pale yellow "	Do	Do	Do	Do	Light green colour	Greenish brown colour
20	White "	Light brown ppt.	Do	Do	Greenish yellow ppt.	Violet brown colour	Reddish brown colour
21	Pale yellow "	Dark brown "	Do	Do	Dirty yellow ppt.	Do	Do
22	White "	Light brown "	Dark brown ppt.	Yellow flocculent ppt.	Do	Greenish brown colour	Greenish brown colour
23	Do.	Do.	Do	Dirty yellow ppt.	Do	Do	Bluish green colour
24	Light yellow ppt.	Do.	Do	Pale pink "	Do	Reddish brown colour	Reddish brown colour
25	Do.	Do.	Do	Light violet "	Bright yellow ppt.	Greenish blue colour	Bluish brown colour

Our best thanks are due to the Superintendent, The Government Opium Factory, Ghazipur, for a liberal supply of narcotine

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# THE EFFECT OF TEMPERATURE ON THE BACTERIAL AMMONIFICATION OF UREA

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Communicated by Prof. N. R. Dhar

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In previous communications from these laboratories, it has been shown that the process of ammonification and nitrification are both partly photo-chemical in nature. The bacterial theory of these processes, which even now holds the field to a larger extent, cannot satisfactorily explain certain experimentally observed facts. The photo-chemical theory advanced from these laboratories for explaining away the two fundamental processes in the plant kingdom, namely, the process of ammonification and the process of nitrification has not to be met with any such difficulty. It can very clearly explain all the experimental observations which have so far remained unexplained by the old bacterial theory. In the present paper, we have undertaken the study of bacterial ammonification of urea with a view to find out the exact temperature limit up to which the process can go on thereby enabling us to arrive at some definite conclusion regarding the possibility of the bacterial process going on in the open sun of the tropics in summer months when the temperature of the soil reaches as high as 60°.

## EXPERIMENTAL

20 g. of air dried fresh soil, after being passed through a fine sieve were taken in a 200 c. c. Erlenmeyer flask. Into the flask were introduced 80 c. c. of a 2% urea solution (the purity of the urea sample used being 95%). The flask was then plugged with cotton wool and kept at a certain

temperature. Duplicate flasks were arranged at each temperature and the mean of the two results obtained with the two flasks at each temperature was taken as the final result.

The flasks were allowed to remain both day and night at each temperature which was maintained with  $0.5^{\circ}$ . At regular intervals, 5 c. c of the solution were sucked out from each flask and the amount of urea left in it estimated by the method described below. This when deducted from the total amount of urea originally present in 5 c. c gave the amount of urea ammonified.

*Method of Estimation of Urea.*—As the ammonification of urea proceeds ammonia gas is liberated some of which escapes to the atmosphere while some remains dissolved in the solution. At every stage, therefore, the solution contains some of this ammonia gas dissolved in it and also the urea left undecomposed. Into a 5 c. c of such a solution, a known volume (in excess) of a standard solution of sodium hypobromite (standardised against standard arsenious acid and iodine solutions) was added. Sodium hypobromite reacted with urea and ammonia liberating free nitrogen, carbon dioxide and water. When the reaction had subsided, an excess of standard solution of arsenious acid was added to neutralise the unused hypobromite left in the solution. The unreacted arsenious acid was titrated against the standard iodine solution. From all these titration results, we could know the amount of sodium hypobromite used up both by urea and ammonia, and thereby, we could calculate out the total amount of nitrogen present in the 5 c. c of the solution in the form of urea and ammonia. The titrations were done with rapidity to ensure correctness and the solution of hypobromite was always standardised before the use.

The amount of ammonia present in the 5 c. c. of the solution was determined separately by means of Dubosque Colorimeter using Nessler's indicator. The colours were compared against a standard ammonia solution.

Subtracting the amount of nitrogen due to ammonia from the total nitrogen due to ammonia and urea both, we found out the nitrogen due to urea alone. This corresponded to the urea left undecomposed in the solution. Deducting this amount from the original amount of urea taken, the amount of urea ammonified was known.

Control experiments were carried on also at all these temperatures under similar conditions but containing no soil. The error in all these experiments was within 0.8 to 1%. Our results are recorded in the following table:—



**Bacterial Ammonification of urea**

5 c.c. of the solution analysed

(5 c.c. of the original urea solution was equivalent to 0.0444 gms N)

Temperature 31°C			35°C		40°C		50°C		55°C	
Time in hours	Ammonified N in gms	% ammonification	Ammonified N in gms	% ammonification	Ammonified N in gms	% ammonification	Ammonified N in gms	% ammonification	Ammonified N in gms	% ammonification
36	0.00195	4.392	0.007613	17.146	0.01628	36.66	0.00005	0.10	0.00004	0.09
60	0.01473	33.18	0.0225	50.7	0.02433	54.8	0.00006	0.11	0.00004	0.09
84	0.02347	52.9	0.0322	72.56	0.03246	73.1	0.000067	0.12		
108	0.02442	55.0	0.03466	78.1	0.03495	78.7				
132			0.0374	84.3	0.0379	85.4				

At 50° and 55°C the amount of the bacterial ammonification was practically the same as in the control ones. At lower temperatures, there was negligibly small amount of ammonification in the control flask.

**DISCUSSION**

The results recorded in the above table clearly show that the optimum temperature for bacterial ammonification in the tropics is near about 40°. In a previous communication, from these laboratories, we had studied thoroughly the temperature effect on the nitrite forming bacteria in the tropical soil and had found out an optimum at 35° for the nitrification. Thus we see that the optimum temperature for ammonification is much higher than the optimum for nitrification. This shows that ammonifying bacteria have a greater resisting capacity with respect to temperature than is the case with the nitrite forming bacteria. A similar relationship has also been noticed by workers in colder countries, though there the optima for nitrification and ammonification are much below those existing in the tropics. This is simply a question of adaptation. In the tropics, the temperatures are always much higher than those existing in the temperate countries and, therefore, the nitrifying and ammonifying bacteria in the tropics have so adapted themselves as to withstand these higher temperatures.

When the amount of ammonification is plotted against time, a S-shaped curve is obtained at temperatures lower than the optimum. This is a common shape for curves showing total growth made after the lapse of a definite period of time and is described as sigmoid. At the optimum temperature, however, the shape of the curve is only partially sigmoid, it is more steep in beginning stages than the curves got at lower temperatures, but in the latter stages, goes on flattening. This is exactly what we should have expected, for in the beginning stages, ammonification rapidly takes place as a result of which the concentration of the urea left is diminished with a consequent decrease in the velocity of ammonification. In the case of nitrite forming bacteria, also similar sort of curves are obtained.

From the table it will be observed that at 50° and 55°, the amount of ammonification is very small and practically the same as that obtained in the control flasks. This clearly shows that the ammonifying bacteria are incapable of existence at these temperatures and, therefore, a complete paralysis of bacteria occurs at these temperatures.

Soil temperature at Allahabad generally reaches 50° at 2 inches depth while about 60° at the surface. Leather observed that at Pusa (India) the soil temperature may rise to 70° at the surface and 60° at a depth of 1 to 2 inches. In other tropical countries also a similarly high temperature of the soil has been found to exist in the summer months. From our experimental results, recorded in the table (page 185), we find that the optimum temperature for bacterial ammonification is near about 40° and that at 50° and 55°, the bacteria are incapable of maintaining their life activity. In view of these observations, we presume that ammonification in the soil of the tropics cannot possibly be much of bacterial origin in the summer months, for an abnormally high soil temperature existing in these months is prejudicial to the growth and activity of the ammonifying bacteria.

### SUMMARY

1. The optimum temperature for the ammonifying bacteria in the tropical soil is near about 40°C.
2. The maximum temperature for the above bacteria seems to be near about 55°C.
3. The soil temperature in tropical soil in summer months exceeds even the maximum temperature for the ammonifiers. Hence in summer ammonification in tropical soil cannot be much of bacterial origin.

# THEVETIN, THE CRYSTALLINE GLUCOSIDE OF *THEVETIA NERIIFOLIA*

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The kernels of the seeds of *Thevetia nerifolia* have been subjected to a series of systematic chemical investigations by several workers. The present author<sup>1</sup> published the results of his chemical examination of the seeds in 1932. Two crystalline glucosides, thevetin ( $C_{20}H_{30}O_6$ ) and thevetoxin ( $C_{16}H_{24}O_8$ ), were isolated in pure forms and their properties were described. Recently Chen and Chen<sup>2</sup> published the results of their analysis of the seeds. They claim to have isolated a phytosterolin and the following three crystalline substances: abouain,  $C_{10}H_{18}O_{10}$ , kokilphin,  $C_{22}H_{42}O_{10}$ , and thevetin,  $C_{20}H_{30}O_{13} \cdot 2H_2O$ .

Thevetin, which is supposed to be the active principle of the seeds, has been given varying chemical formulæ by different workers. They have been recorded in the paper of the latter workers.<sup>2</sup> In page 239 of their paper Chen and Chen remark, "By hydrolysis, Ghatak showed that the sugar component of thevetin was glucose. Assuming for a moment, therefore, the correctness of his formula,  $C_{20}H_{30}O_6$ , the genin of thevetin would be a hydrocarbon, and this is not likely." But in fact this is not the case. On hydrolysis thevetin does not give rise to a hydrocarbon as can be seen from the following reaction:



That thevetigenin is a hydroxy compound has been substantiated by the preparation of an acetylated compound. The acetylated thevetigenin

separates in the form of a pasty brownish mass which solidifies on long standing. The details of further investigations on thevetin will be published in a separate communication

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# NITROGEN FIXATION IN SOILS ON THE APPLICATION OF MOLASSES

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The following lines from Russell's *Soil Conditions and Plant Growth*, 1932, will show that different results have been obtained by different workers regarding the value of sugars in increasing soil fertility and incontestable proof for the fixation of nitrogen on the addition of sugars to the soil is still lacking "Increased yields of sugar cane have followed the application of molasses to soils at the Station Agronomique and on Mr Ebbel's estate in Mauritius, where the residual effect is well shown, and also in Antigua Peck in Hawaii, on the other hand, observed marked losses of nitrate, as also did Harrison in British Guiana" "Laboratory investigations in humid climates suffer from the difficulty that the soils already contain so much nitrogen that small changes are difficult to measure accurately, and there are losses of nitrogen which counterbalance any fixation Investigation would be easier in some of the soils very poor in nitrogen found in hot, arid conditions Rigid incontestable proof could be furnished only by a demonstrated gain in nitrogen effected by *Azotobacter*, all other possibilities being ruled out."

The objects of this investigation are:

1. To find out definitely whether fixation of nitrogen takes place when sugars are added both to sterilised and unsterilised soils.
2. To ascertain the conditions when definite nitrogen fixation takes place on the addition of sugars to the soils and to find out the reason of the failure of several workers on this field.
3. To investigate the possibilities of uses of molasses as a fertiliser.

Experimental procedure:

Soil from the garden was powdered and passed through a sieve to make the grains of uniform size. A portion of this soil was heated to 150° for about 3 hours to sterilise it. The other portion was left as such. 250 g of the sterilised and unsterilised soils mixed with pure cane sugar and 50 c.c. water were spread over in a number of shallow enamelled dishes of 10 inches diameter, and these were exposed to sunlight daily for about 6 to 7 hours for a number of days and the ammoniacal nitrogen

and nitric nitrogen were estimated from time to time The following are the experimental results —

		Unsterilised			Sterilised		
		Ammoniacal nitrogen	Nitrate nitrogen	Total	Ammoniacal nitrogen	Nitrate nitrogen	Total
32 hrs in 10 days	Alone	0 00092	0 000722	0 001642	0 00136	0 000722	0 002082
	20 g. sug	0 0091	0 000781	0 010691	0 00449	0 000728	0 005218
	20 g. sug + 10 g. $\text{Na}_2\text{HPO}_4$	0 01440	0 000721	0 015121	0 00334	0 000742	0 004082
	20 g. sug + 10 g. $\text{CaCO}_3$	0 00952	0 000762	0 010282	0 00333	0 000782	0 004112
80 hrs. in 37 days	Alone	0 00126	0 000729	0 00198	0 00136	0 000731	0 002091
	20 g. sug	0 0135	0 000731	0 01423	0 0073	0 000728	0 01458
	20 g. sug + 10 g $\text{Na}_2\text{HPO}_4$	0 0186	0 000721	0 01954	0 0104	0 0008	0 0184
	20 g. sug + 10 g $\text{CaCO}_3$	0 0136	0 000741	0 01434	0 00688	0 000752	0 007637
103 hrs in 55 days	Alone	0 00126	0 000728	0 001968	0 00126	0 000728	0 001988
	20 g. sugar	0 00151	0 00242	0 00393	0 00221	0 00184	0 00405
	20 g. sug + 10 g. $\text{Na}_2\text{HPO}_4$	0 001008	0 00176	0 00276	0 00137	0 0088	0 010178
	20 g. sug + 10 g. $\text{CaCO}_3$	0 00131	0 00268	0 00379	0 00231	0 00255	0 00486

The soil kept in the dark contained — Ammoniacal nitrogen = 0 00136 g  
Nitrate nitrogen = 0 000728 g

Dark containing 250 g soil (sterilised and unsterilised) 20 g sugar and 10 g  $\text{Na}_2\text{HPO}_4$  after 37 days

	Ammoniacal nitrogen	Nitrate nitrogen
Sterilised =	0 00104	0 00072
Unsterilised =	0 00810	0 00072

50 c.c. of water was added on alternate days

The foregoing results show that both with sterilised and unsterilised soils, the ammoniacal nitrogen goes on increasing up to a limiting value with time, although the nitric nitrogen remains practically constant during this time. After this period, further exposure to light leads to a decrease in ammoniacal nitrogen and an increase of nitric nitrogen but the sum of the ammoniacal and nitric nitrogen is less than that obtained before. This behaviour is due to a loss of nitrogen caused by the photochemical and catalytic decomposition of ammonium nitrite formed on the soil surface. It is well known that 90% of the nitrogen fixed by *Azotobacter* exists as ammonia, and that is why the ammonia increases when the unsterilised

soil is exposed to light mixed with sugar. It is surprising that even in the sterilised soil ammonia goes on increasing. Both the soils were tested bacteriologically after exposure for *Azotobacter* which was readily obtained in the unsterilised soil. After culture only a few could be detected in the sterilised ones. It seems that the combination of nitrogen and oxygen is induced by the oxidation of sugars present in the soil. The nitrite and nitrate formed are readily reduced to ammonia by the reducing action of the sugars, that is why only ammonia is increased and not nitrate. In a recent communication from this laboratory it has been shown that the optimum temperature for nitrogen fixation by *Azotobacter* is  $35^{\circ}\text{C}$  whilst at  $45^{\circ}\text{C}$  practically no nitrogen fixation by *Azotobacter* takes place. It seems, therefore, that the nitrogen fixation during summer days by bacteria will be exceedingly small because they will be mostly killed by the intense heat and light which the soil receives. Our results show that the fixation of nitrogen in the soil by the addition of sugar is helped by light and may take place even in the absence of *Azotobacter*. In the absence of bacteria, hardly any fixation of nitrogen in the soil takes place in the dark.

After obtaining definite evidence regarding the fixation of nitrogen by the addition of sugar both in the sterilised and unsterilised soils, we extended our experiments on the fixation of nitrogen under ordinary field conditions by the addition of molasses. 35 kilos of molasses were added to an area of 500 sq ft and the area was divided into two parts, one part was dug several times after the addition of molasses and the other part was not ploughed. The amounts of nitric and ammoniacal nitrogen present in the soil before the addition of molasses were determined. The amounts of ammoniacal and nitric nitrogen in the molasses were also estimated. In the following table, the ammoniacal and nitric nitrogen contents of the soil before and after the addition of molasses are recorded —

Ammoniacal nitrogen in 50 g molasses	0.046 g
Nitrate nitrogen . . . . .	nil.
1 cubic foot of soil weighs 7 kilograms	
Volume of the soil treated with molasses	$= 18 \times 28 \times 1 = 504$ cubic ft.
wt. of earth	$= 504 \times 7 = 3528$ kilograms.
∴ in 50 g. of soil we have $\frac{1}{2}$ g molasses	
	$= 0.046 \times \frac{1}{2}$
	$= 0.00046$ g. ammoniacal nitrogen
Specific gravity of the molasses	$= 1.302$ .
Molasses added . . .	$= 27$ litres.
∴ the wt. of molasses added	$= 27 \times 1.302 = 35.1$ kilograms.

50 g soil analysed on 24-9-34 before the addition of molasses.

Ammoniacal nitrogen = 0.000483 g, nitrate nitrogen = 0.00119 g.

50 g soil analysed on 24-10-34

Ammoniacal nitrogen = 0.0089 g, nitrate nitrogen = 0.00129 g

The results show that the ammoniacal nitrogen is about 10 times greater in soil after the addition of molasses and aeration even when correction is applied for the ammonia added with molasses. From the experiments it can be concluded that considerable fixation of nitrogen takes place in tropical soils on the addition of molasses provided the aeration of the soil is sufficient. When the aeration is incomplete nitrogen fixation becomes defective, because the energy is necessary for nitrogen fixation and this energy comes from the oxidation of sugars and that is why a large supply of air is necessary.  $N_2 + O_2 = 2NO - 43.2 \text{ Cal}$ . In the absence of air, anaerobic bacteria and fungi flourish and utilise the carbohydrates and nitrate for their growth and hence in the presence of bacteria, instead of addition of nitrogen to soil, nitrate is lost, as has been observed by different people. This can be rectified by increasing the aeration of the soil and thus making the conditions favourable for the oxidation of carbonaceous substances. Hence in order to increase the fertility of the soils by the addition of energy-rich carbonaceous compounds attempts should be made to ensure their proper oxidation by sufficient aeration. Moreover, this oxidation is facilitated by increase of temperature and sunlight and hence there is a great possibility for the utilisation of molasses in India as a manure in increasing the soil nitrogen which is the crying need of tropical soils provided there is sufficient aeration and the soil is exposed to sunlight.

After the addition of molasses on 25th September, 1934, to the soil, a portion of it was carefully turned several times during the course of the month and the other half was left undisturbed. Two other portions of the same field and the same area were utilised for blank experiments without the addition of molasses, one portion of these was dug and turned as many times as the one containing molasses and the other portion was turned only once. Wheat was sown on 25th October, 1934, and at present it is found that the growth of wheat is the best on the portion of the soil containing molasses and well turned over and on the portion containing molasses but not aerated, the growth seems inferior to that on the portion containing no molasses but well aerated by digging.

Many workers have failed to obtain nitrogen fixation in soils by the addition of carbohydrates. Our experiments show that the failure is mainly due to the insufficiency of aeration of the soil.



# CYTOPLASMIC INCLUSIONS IN THE OOGENESIS OF *MUSCA DOMESTICA*

BY MURLI DHAR LAL SRIVASTAVA

Communicated by Prof D R Bhattacharya

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## INTRODUCTION

The oogenesis of insects is specially interesting as, besides the study of the structure, behaviour, and functional significance of the various cytoplasmic components, it entails the elucidation of a variety of other problems, such as the origin and differentiation of the follicular cells, nurse-cells, and oocyte, the role of the follicular cells and nurse-cells in the growth and development of the oocyte proper and their ultimate end, the origin, function, and fate of the accessory nuclei, the origin, nature, and significance of the "germ cell determinant," etc

The oogenesis of *Musca domestica* was undertaken to determine the structure and behaviour of the various cell organelles during the changes undergone by the developing egg, and also to attempt to shed further light on some of the other problems mentioned above

A separate historical account has been omitted. The works of the previous authors have been referred to, wherever necessary, under the "Discussion", and a brief list of the literature on the subject is given at the end.

This piece of research was carried on in the Zoological Laboratory, Allahabad University, under Professor D R Bhattacharya to whom my cordial thanks are due for his help and guidance

## MATERIAL AND METHOD

Adult specimens of *Musca domestica* were collected near about the Laboratory. The insects were dissected out in the physiological salt solution and the ovaries were quickly transferred to the various fixatives, thus reducing the chances of artefacts to a minimum

For the demonstration of the Golgi bodies Ludford and Mann Kopsch methods were employed. Cajal and Da Faho preparations were made only for the purposes of control. F W A and Champy Kull methods were employed for the mitochondrial preparations, keeping Regaud and

Regaud-Tupa preparations as control Bouin was used for studying the general structure of the eggs

#### GENERAL STRUCTURE OF THE OVARIOLE

As characteristic of the diptera, the construction of the ovarian tubules follows the ordinary poly-trophic pattern. To the naked eye the ovary presents the appearance of a compact globular mass, and the resemblance of the ovarioles, when separated, to a beaded string with distinctly marked swellings is rather weak. Unlike hymenoptera there are no distinctly separate nutritive chambers formed by a constriction between the oocyte and the nurse-cells developed in association with it, and the entire ovariole is exceedingly short, consisting of an "end chamber" and two or three follicles with the mature egg, if present, at the posterior extreme.

The extreme anterior end of the ovarian tubule, the "end chamber," is apparently a cysstical mass closely packed with a large number of nuclei (Figs 1, 5, 12). Confined mostly to the periphery, but occurring also in the interior, are a number of narrow rather elongated nuclei with generally a single granule inside (Figs 1, 12). These are identified as the nuclei of the future follicular epithelial cells. Then there are a number of bigger nuclei with generally a single grain of nuclear matter. These are indifferent cell nuclei which form the nurse cell and oocyte nuclei (Fig 14). Still another kind of nuclei are circular in shape and contain irregular clumps of sharply staining nuclear matter. The spireme threads are not visible in any. These nuclei are very much alike and can be distinguished as the nurse-cell nuclei, but the oocyte nuclei are not seen with certainty at this stage, though some doubtful indications are at times observed.

The egg follicles of the tubule are produced by a constriction in the end chamber, which eventually separates off a part of it consisting of an oocyte nucleus, several nurse-cell nuclei (mostly seven), and a large number of follicle cell nuclei. The youngest egg follicles that were detected showed a number of follicle cell nuclei irregularly distributed on the periphery (Figs. 2, 13). The oocyte nucleus is easily distinguishable at the stage represented in figure 2, though the nuclei shown in Fig 13 are all nurse cells and there is no clearly differentiated oocyte nucleus. The oocyte nucleus contains a few (one or two) sharply staining granules and there is a faint indication of a reticulum. Otherwise it is a perfectly clear structure. The nurse-cell nuclei, on the other hand, are completely filled with a great number of prominently staining clumps of varying size. A narrow cytoplasmic zone, much more strongly staining than the rest of the cytoplasm, borders the greater

length of the nuclear membrane. The egg-follicle at this stage is a spherical structure consisting of an irregular wall of varying thickness, built up of the follicular cell nuclei, and an interior lodging the nurse-cell nuclei and the oocyte nucleus. The haphazard distribution of the follicular cell nuclei on the periphery immediately gives place to a more definite arrangement. The nuclei get regularly arranged on the periphery and are closely approximated (Fig 3). This regular arrangement of the follicular nuclei obtains in many cases even when the constriction has just begun and is still proceeding. As the growth proceeds the follicle gradually loses its spherical shape and becomes drawn out into a more or less oval structure (Fig 3). The narrow dense cytoplasmic zone, embracing the oocyte nucleus (Fig 2), gradually extends till it completely encircles it (Figs 3 and 14). The cytoplasm immediately surrounding the nurse-cell nuclei stain a shade deeper than the rest but no indication of the formation of definite cell membranes are found (Fig 2, 3, 13, 14). Shortly afterwards, the initiation of the production of the partition membranes becomes distinctly perceptible. The follicle cell nuclei, however, remain naked for a considerable length of time onwards, and the walls are not perceptible long after the nurse-cells and the oocyte are partitioned off (Fig 15). The nurse-cells, though close together, never form a "nutritive chamber" in the strict sense of the term, as they are separated from the oocyte only by prominently staining membranes—the nurse cell walls. There is no constriction between them and no follicular epithelial cells intrude. The follicular epithelium uniformly covers the entire egg without a break (Fig 16).

At the extreme posterior end are found the mature eggs. There is no remnant of nurse-cells left in association with the oocyte, and no trace of them is found in the egg, which is entirely filled with yolk. The entire egg is enclosed in a vitelline membrane, which is covered with a chorion envelope built of polygonal areas with prominent nuclei and knob-like processes. Distributed through the entire cytoplasmic mass of the "end chamber" are a number of osmiophilic granules (Fig 1, 7). These are identified as Golgi bodies. No mitochondria could be detected in this part of the ovariole (Fig 12).

The cytoplasmic inclusions of both kinds, the Golgi bodies and mitochondria, are found irregularly distributed throughout the follicles (Figs. 2, 3, 13, 14) and show no tendency towards a special juxtanuclear aggregation during the early stages. Golgi bodies were easily detected in the follicular area (Figs. 2, 3), though the nuclei are so closely approximated there as to leave little cytoplasmic area unoccupied. But

the closest search failed to reveal the presence of mitochondria in this region due, no doubt, to technical difficulties.

#### NURSE CELLS

A number of nutritive cells develop in association with the oocyte proper, and throughout their life-time secrete and discharge nutritive material into the oocyte, and thus contribute towards the growth and development of the egg. During the early stages they are not marked off from each other, but as the egg follicles grow they get separated from each other and the oocyte by distinct thin membranes (Figs 4, 6, 7, 8). Their nuclei have thick nuclear membranes, and the nuclear matter exhibits a faintly staining complicated reticulum with irregular clumps and small granules of strongly staining matter distributed haphazard all through the nucleus. These masses stain red with acid fuchsin, deep blue with hæmatoxylin, and appear greyish to black in osmic-treated material.

At first, for a considerable length of time, the nurse-cells form by far the greater bulk of the entire egg-follicle (Figs 4, 6, 7, 8, 16), but as growth proceeds they gradually diminish in size, and later on a reversibility in the comparative size of the oocyte and the mass of nurse cells attached to it gets established.

The nurse-cells contain both types of cytoplasmic inclusions in abundance. The Golgi bodies, as recorded above, are seen even in the end chamber. Quite a large number of them is found irregularly distributed in the youngest egg-follicles (Figs. 2 and 3). In fully formed nurse cells they are uniformly scattered through the cytoplasm (Fig. 11). At no stage do they show any special concentration on the nuclear membranes or the nurse-cell partition walls. The Golgi bodies appear as homogeneous deep black granules and don't exhibit any sign of the presence of the osmiophilic cortex and osmiophobic interior. Probably it is due to over-osmication. The Golgi bodies are very well studied in fresh untreated material in normal saline. They are observed as small refringent granules filling the entire cytoplasm of the nurse-cells. On exerting a slight pressure of the cover-slip the egg is ruptured. The Golgi bodies are thrown out and begin executing an interesting vibratory motion, which continues for a long time.

The mitochondria, like the Golgi bodies, are clearly seen in very young egg-follicles (Figs. 13, 14). They are in the form of deeply-staining homogeneous grains and in the fully-formed nurse cells are distributed all through (Fig. 16). Some of the granules align to form beaded chains, but no filaments were found. They show no tendency towards aggregation on the nuclear membranes, but are found in

a greatly concentrated condition on the nurse-cell partition walls (Figs 16, 18, 19).

As mentioned before, the mass of the nurse-cells is separated from the oocyte by the intervention of the nurse cell partition membranes. Parts of these membranes at times ruptures, thus establishing a direct continuity of the nurse-cell cytoplasm with that of the oocyte. And through this opening a regular stream of the nurse-cell Golgi bodies inflows into the oocyte (Fig 7)

Fig 11 represents quite an advanced egg. The oocyte cytoplasm is densely packed with albuminous yolk-bodies. The membrane separating the nurse-cell to the left and the oocyte has disappeared, and just beneath, in direct continuation with nurse-cell cytoplasm, is a nearly triangular area of similarly clear granular cytoplasm, exhibiting a strong contrast to the rest of the oocyte cytoplasm and studded with yolk spheres. The appearance presented is a strong evidence of a direct transference of the nurse-cell cytoplasm together with its Golgi bodies to the oocyte. And appearances indicate that, even while the barrier separating the nurse-cell and the oocyte is intact, the Golgi bodies of the nurse-cell infiltrate into the oocyte (Figs 8 and 9) through the partition membrane.

A similar behaviour on the part of the mitochondria is also revealed. In the egg-follicle represented in Fig 16 the separating membrane is quite intact, but appearances are strongly suggestive of the infiltration of the nurse-cell mitochondria into the oocyte. Fig 22 represents a part of a more advanced egg follicle in which the separating membrane has disappeared at places leaving wide openings. Through these gaps the mitochondria-laden sheets of cytoplasm are being transferred to the oocyte.

As a consequence the nurse-cells dwindle while the oocyte increases in bulk, since its development progresses at their expense.

The nurse-cell nuclei are never observed to disintegrate, fragment, or pass directly into the oocyte, and no trace of them was found in the mature egg.

In some advanced eggs it was found that the barrier separating the ovary and the nurse cell had disappeared, and the mitochondria-laden cytoplasm of the oocyte was in closest contact with the strongly contrasting yolk-studded oocyte. The nuclear matter of the nurse-cells had stained much more feebly, and there appeared some evidence of an approaching disintegration. It lends some possibility to the suggestion that the nurse-cells are ultimately absorbed by the oocyte, but this is not established by evidence furnished by direct observation. In all probability the remnant of the nurse-cell mass is finally cast off.

## FOLLICULAR CELLS

Follicle cells are formed by the small narrow and rather elongated nuclei noted in the end chamber (Figs 1, 12). In young follicles these naked nuclei, by their close approximation, form a regular peripheral zone (Figs 2, 3, 13, 14), and it is much later that distinct cell walls appear. During the early stages the follicular epithelium forms an uninterrupted single-layered envelope round the entire egg follicle (Figs 4, 6, 7, 8, 16), but as development proceeds, they gradually dwindle in the nurse-cell regions (Fig 21) and ultimately almost entirely disappear (Figs 11, 20.) It is usual to find in fairly advanced follicles a few solitary follicular cell nuclei still attached to the periphery of the nurse-cells, when by far the greater number have disappeared (Fig 11). In a few cases when the nurse-cells region becomes devoid of the follicular epithelium, a few follicular cell nuclei are observed to invade the nurse-cell cytoplasm and come to lie in the proximity of the nucleus. The phenomenon, however, seems to be of exceedingly rare occurrence.

Follicular cells contain both kinds of cytoplasmic inclusions, *i.e.*, the Golgi bodies and mitochondria, scattered on both sides of the nucleus, *i.e.*, facing the periphery of the oocyte and on the opposite side (Figs 9, 10, 17, 18, 19, 21). In some cases the Golgi bodies of the follicle cells show a special concentration on the membrane separating them from the oocyte, and a closer observation reveals an infiltration of these granules into the oocyte (Fig 10). The morphology of the follicular Golgi bodies is similar to that of the nurse-cell Golgi bodies.

The mitochondria of the follicular cells are uniformly scattered and show no special orientation. They were not observed to filter down into the oocyte. Structurally they resemble the nurse-cell mitochondria and are in the form of spherical granules. They never align to form beaded chains as they do in the nurse-cells.

As the egg-follicles develop, and the follicular cells get partitioned by the formation of distinct cell walls, some of them present a remarkable phenomenon. These cells begin darkening on one side of the nucleus (Fig 17), and this proceeds (Figs 18, 19) till eventually the entire cell gets uniformly darkened. The ultimate result of this process is that the affected cells even lose their cellular character, and are reduced to non-cellular longitudinally striated dark patches extending parallel to the ordinary follicular cells. A close observation brings to notice the presence of many dark granules in the interior of such cells (Figs. 18, 19). This darkening of the follicular cell is by no means confined to the oocyte

region, but, on the contrary, occurs all over indiscriminately. The extremity of this non-cellular patch later on projects into the interior, but the appearances are not indicative of an actual transfer of any granular substance into the oocyte. Gradually it diminishes, the projecting end is thrown into folds, and in the later developmental stages they cannot be traced. The mature egg is completely devoid of the follicular cells, a chorion membrane formed by them covers the egg instead.

The vitelline membrane begins to appear as a distinctly new structure in the follicle represented in the figure 19. With the general development of the egg-follicle it gets thicker and tougher and is a prominent structure in the ripe egg.

At times the follicular cells show a remarkable abnormal activity. They multiply greatly in number, invade the oocyte, and gradually eat it up.

#### SECONDARY NUCLEI

In many early follicles, before the nurse-cell walls are laid down, the nuclear membranes of the nurse-cells are covered with fuchsinophil granules obviously in the act of passing out (Figs. 13, 14). The tendency of these nurse-cell nucleolar lumps towards fragmentation and extrusion becomes very strong during later stages. In fairly advanced follicles the process is of a very wide occurrence and is remarkably prominent. In the follicle represented in Fig. 20 the actual passage of nucleolar pieces into the nurse-cell cytoplasm is clearly seen. After passing out through the thick nuclear membrane these fragments obviously break up into still finer pieces, and then each gets surrounded by a thin, but remarkably distinct, membrane. The result of the process is the formation of a number of minute bodies resembling miniature nuclei. These bodies have been called "Accessory" or "Secondary" nuclei. In rather rare cases the area enclosed within the secondary nuclear membrane is nothing different from the surrounding cytoplasm in staining reaction, but in most it is an entirely clear unstaining structure, while the nurse-cell cytoplasm is darkly stained and packed with the cytoplasmic inclusions (Figs. 20, 21). It is a sharp clear vesicle bounded by a definite membrane and lodging a single nucleolar granule without a reticulum. They are not formed far from the nuclei responsible for their origin, but later on they migrate to the centre of the nurse-cell mass (Figs. 20, 21). As many as seven were counted in some cases. They do not maintain this central position for long but, on the contrary, shortly afterwards they begin to move down-

wards towards the oocyte, and ultimately come to rest on the partition membrane separating the oocyte from the nurse-cell mass. This downward movement does not occur in a mass, but, on the contrary, the individual nuclei migrate separately. On the partition wall they are enclosed together with a certain quantity of cytoplasm and the inclusions by a membrane, thus forming a separate chamber (Fig 22). The secondary nuclei were not traced after this. Possibly they get absorbed by the oocyte, but on account of its interior being choked with yolk bodies they cannot be traced as such in it. Or they disintegrate and disappear.

## THE OOCYTE

### GOLGI BODIES

In the youngest follicle obtained the Golgi bodies are observed as a few small irregular deep black granules easily noticeable on the dense juxtanuclear cytoplasmic zone (Fig 2). As already noticed, this area grows and eventually encircles the entire nucleus (Fig 3). Simultaneously the Golgi bodies increase in number and undergo a free scattering. Before the partition walls are laid down, and for sometimes even afterwards, the Golgi bodies are uniformly distributed. In later stages the Golgi bodies aggregate to form a juxtanuclear mass of clustering granules (Figs 4, 6). This mass grows bigger by the multiplication of the Golgi bodies, but after a short period it disorganises, and the granules undergo a more or less uniform dispersal throughout the cytoplasm.

On account of the re-enforcement of these bodies by a passage of similar granules from the follicular epithelium and the nurse-cells two specially concentrated bands of them get established, one beneath the membrane separating the oocyte and the nurse-cells and the other beneath the partition line of the follicular cells and the oocyte (Figs 8 and 9).

In more advanced eggs the Golgi bodies are scattered amongst the yolk bodies which fill the entire cytoplasm of the oocyte (Fig 11).

The Golgi bodies of the oocyte like those of the nurse-cells and follicular epithelial cells appear as homogeneous uniformly blackened granules and do not show the densely staining rim and the clear centre. Apparently they take no part in the process of vitellogenesis, and are easily seen as refringent granules in fresh material without the application of any reagent.

### MITOCHONDRIA

Like the Golgi bodies the mitochondria appears as a few discrete granules easily distinguishable on the dense cytoplasmic area closely



applied to the nuclear membrane (Fig. 14) With the growth of the egg they increase in number and are in a freely scattered condition during the early stages Later on, however, they form a juxtannuclear mass of closely packed granules situated on a dense cytoplasmic sub-stratum (Fig 15) This mass, however, does not persist long, but shortly afterwards breaks up, and the individual granules are freely scattered (Fig 16) They are uniformly distributed and do not show any special concentration as noted in connection with the Golgi bodies During these growth stages they are reinforced by a passage of nurse-cell mitochondria infiltrating in regular streams through the intervening membrane (Fig 16), or brought in during the later stages by the nurse-cell cytoplasm pushing its way into the oocyte (Fig 22). They are strongly fuchsinophil granules and stain bluish-black by iron alum hæmatoxylin Mitochondria in the form of filaments or beaded chains were not detected in the oocytes at any stage They play a significant part in the process of yolk-formation In older eggs the cytoplasm is so closely packed with yolk spheres that they are detected with difficulty in finished sections

### YOLK BODIES

Only one kind of yolk is found in the eggs of the animal under investigation, *i.e.*, albuminous yolk These yolk bodies are strongly fuchsinophil and stain deep blue with iron alum hæmatoxylin They are tinged yellowish by chrome-osmium fixatives and are preserved by non-osmic techniques like those of Cajal and Da Fano They tinge yellow to blackish by Mann-Kopsch and Ludford fixatives but are completely decolorised on a few seconds' treatment with 1% potassium permanganate followed by oxalic acid

The deposition of yolk particles commences only after the oocyte is definitely partitioned off from the nurse-cell mass, and the process does not occur all over simultaneously, but is confined to the immediate neighbourhood of the nucleus (Figs 6, 15, 16) This area, as recorded before, is also the seat of the concentration of the other cytoplasmic components, and as this mass breaks up and the inclusions are scattered, the yolk-spheres likewise begin to move away (Fig 9), and during the later stages are uniformly scattered. In older eggs they fill nearly the entire egg, leaving free only a narrow peripheral cytoplasmic area, "periplasm, or perivitellus," and an anteriorly situated portion lodging the nucleus In mature eggs they fill the meshes of the reticulated cytoplasm

These bodies are produced by the swelling up of the mitochondrial granules, which gradually transform into yolk (Figs 15

and 16) All stages between the small deeply-staining granule and the big spheres of yolk are perceptible. These yolk bodies are poorly preserved in Bouin's Fluid and are best fixed and stained by techniques used for the demonstration of the mitochondria—facts that also lend support to the conclusion that they are not produced independently by the ground cytoplasm, but by the activity of the mitochondria.

Intravital they appear as transparent, colourless, homogeneous spherules.

### NUCLEOLAR EXTRUSION

The process of nucleolar extrusion is restricted to a short period and does not appear to be a widely occurring phenomenon in the oocytes of *Musca*.

At a certain stage of the growth of the egg-follicle, when it has assumed the oval form and the different cells are marked off by membranes, the nucleolus of the oocyte nucleus manifests signs of intense activity (Figs 15, 16, 17). It has increased vastly in size and is undergoing budding, throwing off the fragments through the body of the nucleus. Some of these fragments obviously migrate through the nuclear membrane—though it does not show any sign of injury—and are found in the oocyte cytoplasm in close proximity of the nucleus (Figs. 16, 17). This process occurs as the deposition of yolk commences, but apparently the extruded particles take no part in it. The nucleolar fragments, when thrown into the oocyte cytoplasm, do not undergo any change in staining reactions, and do not grow in size. They simply disappear after a short interval, leaving no mark of their presence. The nucleoli stain deeply with acid fuchsin and iron-alum haematoxylin.

### EGG-MEMBRANES

As noted previously, at a certain stage in the development of an egg-follicle, indicated in Fig. 19, a new membrane begins to appear between the follicular epithelium and the oocyte periphery. This membrane in the older eggs is gelatinous, deeply-staining, and rather thickish, and often spreads out into the oocyte. As represented in Fig. 19, its secretion begins at a period when the nurse-cell and the oocyte constituting the follicle are thoroughly marked off by the formation of distinct cell membranes, and the process of yolk deposition has already progressed to a good extent. The follicle cells have secreted their cell walls and some have begun darkening. Its formation progresses with the general growth

of the egg till it forms a continuous membrane intervening throughout between the oocyte periphery and the follicular epithelium (Fig 11) It never extends to the nurse-cell region and stop short at the region where the oocyte is separated from the nurse-cells by nurse-cell membranes The vitelline membrane eventually bends round the corner and begins to intervene between the nurse-cell mass and the oocyte which were formerly separated by nurse-cell membranes alone This process begins to occur in highly advanced follicles The mature egg is completely surrounded by it The vitelline membrane is secreted by the oocyte, and not follicle cells, as it is also present where there is no follicle cell, *i.e.*, the border line of the nurse-cells and the oocyte

The mature egg is enveloped in a hard and brittle covering which is a very great impediment in sectioning such eggs This structure is formed by the follicular epithelium which is completely absent at this stage It is very well stained with acid fuchsin and eosin is distinctly divided into regularly fitting polygonal areas thickly studded with knob-like processes, and shows a number of nuclei prominently staining with hæmatoxylin (Fig 23)

A thin structureless basement membrane is made out investing the egg-follicle just on the outside of the follicular epithelium (Figs 4, 6, 7, 10) It cannot be made out as a separate structure after the chorion membrane has been formed, having been used up in its production.

## DISCUSSION

### NURSE-CELLS

The exact morphological relationships of the three kinds of cellular elements, *i.e.*, the oocyte, the nurse-cell, and the follicular cell, found in the ovaries of insects, has long been a matter of controversy They seem to arise in different ways in different groups of insects.

Kahle ('08) and Hegner ('14) showed that the nurse-cells and the follicular cells of the ovary of *Miastor* are of mesodermal derivatives, while the oocyte proper alone is formed by the germ-cells On the other hand, the observations of other investigators indicate a common germ-cell origin for the nurse-cells, the follicular cells, and the oocytes. (Korschelt '86 in *Bombus*, Paulke in *Apis* '01, Marshall '07 in *Polistes*—all these being hymenopterous insects.) Similarly Giardiana in *Diastiscus* and Jorgensen in *Pisciola* ascribe a common origin to the oocytes and the nurse-cells,

and the observations of Dederer and Hogben bear evidence to the same effect (Wilson '25) The end chamber of the ovary of *Musca* shows only two kinds of nuclei different in size and shape The smaller ones are responsible for the formation of the follicular cells and from the bigger differentiate the nurse-cells and the oocyte It is difficult, thus, to resist the conclusion that the nurse-cells and the oocytes have a common origin, but whether the follicular cells have a common origin with the other two types of cells or not cannot be definitely established by evidence available in the present case In all probability they are not

Whether the nurse-cells can be regarded as abortive rudimentary eggs or not, there is little doubt about the fact that they are specialized nutritive cells that during the growth of the oocyte elaborate and discharge nutritive material into the functional ovum (Nussbaum-Hilarowicz '17 on *Dysticus*, Wieman '10 on *Leptinotarsa*, Paulke in honey bee, Nath in *Culex* '25, Nath and Bhandari '30 in *Dysdercus cingulatus*) Paulke wrote that in the honey bee the nurse cells secrete and discharge nutritive material into the oocyte, and Nussbaum-Hilarowicz in *Dysticus* showed the transference of nurse-cell inclusions into the oocyte through protoplasmic bridges established between the nurse-cells and the oocyte

Peacock and Gresson ('27) working on certain Tenthredinidae showed the passage of a regular stream of granular cytoplasm with degenerating secondary and nurse-cell nuclei from the nutritive cells into the oocyte. Similarly the absorption of continuous sheets of nurse-cell cytoplasm together with nuclei by the oocyte was shown by Nath ('24) in *Culex* Paulke found the presence of nurse-cell nuclei in the upper part of the oocyte and concluded the entire absorption of the nurse-cells by the oocyte Fragments of nurse-cell nuclei in the oocyte were also detected by Snadgrass, who came to the same conclusion Peacock and Gresson ('27) figured the inflow of nurse-cells nuclei into the oocyte and showed the absorption of the nurse-cells by the oocyte.

The inflow of the mitochondrial and Golgi granules of the nutritive cells into the oocyte is strikingly conspicuous in the present case Likewise is the partial absorption of the nurse-cell cytoplasm But whether the nurse-cells are entirely absorbed by the oocyte or a disintegrating remnant is eventually cast off, as shown by Nath in *Culex*, is not definitely established.

### FOLLICULAR EPITHELIUM

Marshall ('07) in hymenoptera, Vejdovsky ('11, '12) in an isothoptera, Dederer ('17) in lepidoptera conclude a common origin for the

follicle cells and the oocyte Hey's ('95) conclusions, on the other hand, ascribed a mesoblastic origin to the follicle cells. The investigation of the ovary of the adult *Musca*, does not afford sufficient data to solve the question definitely one way or the other. The end chamber contains already conspicuously differentiated nuclei.

Peacock and Gresson, in certain Tenthredinidæ described a peculiar darkening of some follicular cells. They traced the formation of the secondary nuclei ('27) to the grains discharged by these cells. This was, however, contradicted by Gresson in a later paper.

In the present case these dark cells are a striking feature of the follicular epithelium of eggs at a certain stage. Eventually these cells get reduced to granule-filled dark non-cellular masses, that project but apparently do not discharge any granules into the oocyte.

It may not be out of place to mention here that such a darkening of certain follicular cells has been recorded in vertebrate eggs (Holl, Brambell, Mertens, Das, and Srivastava). Hall ascribed a mechanical function to it.

In *Musca* the process is confined only to eggs at a certain stage of development.

### SECONDARY NUCLEI

Secondary nuclei have been observed in the eggs of different groups of insects by various authors (Blochman '84, '86, Korschelt '86, Stuhlman '86, Marshall '07, Will '84, Ayres '84, Gross '03, Loyer '08, Hegner '15, Gatenby '20, Peacock and Gresson '27). The account of their manner of origin varies greatly, and in some cases conclusions are based on mere inferences. Will ('84) and Ayer ('84) considered them follicular epithelial cells; Korschelt likewise derived them from follicular cells, Gross derived them from the epithelium and nurse-cells, Blochman and Hegner, separately, in honey bee from follicular epithelium, Marshall thought they arose by the budding of the germinal vesicle, Loyer concluded that they arose from all the three sources "mais résultent d'une coagulation de substances venues du dehors de l'oeuf," Hegner thought that they were not derived by actual budding but by nuclear substances thrown off by the oocyte nucleus into the cytoplasm. In *Rhotide ignota* Hegner considered them derived from the chromatic particles thrown off by the nurse-cell nuclei, follicular nuclei, and oocyte nucleus.

Gatenby in *Apanteles* showed the origin of the accessory nuclei from chromatic particles emitted by the oocyte nucleus, and Peacock and Gresson derived them from oocyte nucleolar budding, chromatin particles

emitted by the nurse-cell nuclei, and the particles emitted by the follicular cells Mukerjee ('30), however, showed by the Fenlgen's method that the secondary nuclei contain no chromatin. And Gresson ('30) disproved Peacock and Gresson's conclusions as to the manner of their origin, and was inclined to accept Hogben's ('20) conclusion that they are merely vacuolated nucleolar bodies.

In the material under investigation some follicular cell nuclei have actually been observed migrating into the nurse-cells, and in the interior they bear a striking resemblance to the accessory nuclei. Nevertheless, the present writer does not consider it established as the phenomenon seems of very rare occurrence and it is difficult to distinguish between the invading follicle cell nuclei and the true secondary nuclei of the nurse-cell origin.

In spite of some follicular cells undergoing processes similar to those described by Peacock and Gresson, it is not possible to ascribe the formation of secondary nuclei to the particles infiltrating from these affected cells. No secondary nucleus was observed arising in this way. In fact the oocyte proper never showed the presence of any accessory nucleus in it. And likewise, though the extrusion of the nucleolar buds of the oocyte nucleus does occur, it was never observed originating secondary nuclei.

In *Musca* the accessory nuclei arise only in one way, i.e., from the nucleolar particles thrown off by the nurse-cell nuclei. The extrusion of particles has been actually observed. Such particles get enclosed by a membrane and finally appear as accessory nuclei. The present writer does not consider them as merely vacuolated nucleolar bodies but distinct secondarily formed structures. The accessory nuclei have not been shown in the present case to inflow into the oocyte as figured by Peacock and Gresson, and also shown by Buchner. And they come to rest on the membrane separating the oocyte and the nurse-cells when the process of the deposition of yolk has considerably advanced. Obviously they can play little direct part in vitellogenesis.

## OOCYTE

### GOLGI BODIES

The Golgi bodies of the eggs of *Musca domestica* present the appearance of intensely osmiophilic homogeneous spherules. At no stage do they show the characteristic chromophilic cortex and chromophobic centre (Nath, 14, 15, 16; Gresson 5, 7). Nor are they in the form of a

complicated reticulum, battonets, chains, crescent or rodlets (Bhattacharya '25) They take no part, direct or indirect, in the process of yolk deposition and thus apparently serve no nutritive function, as has been shown in some insects (Nath and collaborators 15, 16; Gresson, 5, 7)

No apparent fragmentation of the Golgi bodies was observed, and yet the enormous growth of the bodies in number during the development of the oocyte would warrant a conclusion to that effect The Golgi bodies are found even in the mature eggs, though the cytoplasm in such cases is thickly crowded with yolk spherules

It is a remarkable fact that the Golgi bodies in this material are seen with striking clearness without the use of any stain Nath in *Culex* and Nicholson in *Anophelis* record a similar experience An intravital examination of these bodies gave no indication of a duplex structure

### MITOCHONDRIA

The mitochondria have been shown to play no important rôle in the nutrition of the eggs of other insects (Nath and co-workers 15, 16, Gresson 5, 7), except by Hegner in *Leptinotarsa* In the present case they fulfil a highly important function, *ie*, the production of reserve food material, and have been shown to undergo a direct transformation into albuminous yolk spherules The importance of mitochondria in the eggs of *Musca* is thus greater than in those of other insects

Nath ('29) records the absence of mitochondria from the eggs of *Culex*, while Nicholson in *Anopheles maculipennis* makes no mention of it Nicholson, however, was not concerned with the cytoplasmic inclusions of the eggs In the eggs of *Musca* mitochondria are convincingly seen at all stages, and there can be no doubt as to their presence

### YOLK

An abundance of albuminous yolk fills the eggs of *Musca domestica*, but there is entirely no fatty yolk A similar absence of fatty yolk in the eggs of mosquitoes, *anopheles* and *Culex*, is apparent on a perusal of the papers by Nicholson ('21) and Nath ('29) The smaller type of yolk granules occurring in the eggs of *Anopheles* (Nicholson) are, as shown by Nath, nothing but the Golgi bodies In the present case it has been concluded that yolk results from direct transformation of mitochondria In other insects different conditions appear to obtain

(Nath '29, Nath and P Mohan '29, Nath and Mehta '29, Gresson '29, '31) They arise independently in the ground cytoplasm or are formed by the transformation of nucleolar extrusions

### NUCLEOLAR EXTRUSION

The nucleolar extrusion in this animal is of an extremely simple and uncomplicated nature. It does not give rise to yolk bodies as recorded in some insects (Hogben, Gresson, Nath and collaborators). At no stage does the nucleus behave in the extraordinary fashion recorded by Nicholson. The nucleolus remains basophil throughout, and the emission of its fragments is confined to a limited period and does not last throughout the oogenesis as recorded by some in other insects (Blandari and Nath). During the later stages of oogenesis the nucleolus even fails to appear. It never assumes vacuolated appearance (Gresson in some *Tenthredinidae*, Hogben, Nath, and Gresson in *Periplaneta*).

The nucleolar emission in the present case is so spare, and is confined to such a short period, that it is not surprising to find that extrusions do not give rise to yolk bodies. The emission of the nucleolar buds, however, synchronizes with the deposition of yolk.

### SUMMARY

1. The end chamber is a cysytium lodging a number of follicle cell nuclei, indifferent nuclei, and, later, nurse-cell nuclei. The oocyte nuclei generally are not seen at this stage. The Golgi bodies are traced but no mitochondria were detected.

2. A part of the end chamber constricts off and forms an egg follicle consisting of a wall built of naked follicle cell nuclei and an interior lodging generally seven nurse-cell nuclei and one oocyte nucleus. The cytoplasmic inclusion of both types are found.

3. The nurse-cells and oocyte, later on, get partitioned off by distinct cell-membranes.

4. The nurse cell mitochondria and Golgi bodies infiltrate into the oocyte, and inclusions—laden nurse-cell cytoplasm stream into the oocyte.

5. Mitochondria give rise to albuminous yolk.

6. Secondary nuclei are formed by nucleolar particles emitted by the nurse-cell nuclei.

7. Golgi bodies infiltrate from the follicular epithelial cells into the oocyte.



8 Nucleolar extrusions spread over a small period and the process is very simple. The extrusions take on part in vitellogenesis

9 A peculiar darkening of follicular cell has been described

10 A vitelline membrane is secreted by the oocyte cytoplasm and the follicular epithelium produces the chorion

11. The mature eggs contain no remnant of nurse-cell nuclei or accessory nuclei

#### EXPLANATION OF LETTERING

AL Y B	Albuminous Yolk Body
B M	Basement Membrane
E C	Epithelial Cell
G B	Golgi Body
CY INF	Cytoplasmic Inflow
N C.	Nurse-Cell
N. C N	Nurse-Cell Nucleus
V M	Vitelline Membrane
F E.	Follicular Epithelium
O N	Oocyte Nucleus
O Nu	Oocyte Nucleolus
G B INF	Inflow of Golgi Bodies
O	Oocyte
N C. M	Nurse-Cell Membrane
M	Mitochondria
INF M	Infiltration of Mitochondria
Nu. EX.	Nucleolar Extrusion
D. C.	Dark Cells
S N	Secondary Nucleus
N C P	Non-Cellular Patch
F C. Nu	Follicular Cell Nucleolus
INF G B.	Infiltration of Golgi Bodies
F G B	Follicular Golgi Bodies
F C M.	Follicular Cell Mitochondria.

#### EXPLANATION OF PLATES

- Fig. 1.** End chamber showing epithelial cell nuclei and nurse-cell nuclei and a few Golgi bodies. Mann-Kopsch.
- Fig. 2.** A young follicle; follicular cell nuclei are thrown to the periphery and the nurse-cell and oocyte nuclei have become differentiated.

Golgi bodies are distributed haphazard all through and a dense cytoplasmic zone has appeared embracing a part of the oocyte nuclear membrane. Mann-Kopsch.

- Fig 3. A slightly older stage than that shown in Fig. 2. Golgi bodies have increased in number and the dense cytoplasmic zone completely surrounds the oocyte nuclear membrane. Mann-Kopsch
- Fig. 4. A still older egg than that shown in Fig 3 Golgi bodies of the oocyte form a concentrated juxtannuclear patch. Nurse-cell and oocyte partition membranes have formed. Ludford
- Fig 5. End chamber showing Golgi bodies. There is some indication of the differentiation of oocyte nucleus. Ludford
- Fig. 6 Nearly the same stage as shown in Fig. 4 The juxtannuclear patch of Golgi bodies of Fig 4 now completely surrounds the nucleus. Albuminous yolk bodies have appeared. Ludford.
- Fig. 7. An older egg-follicle than that of Fig 6 Part of the membrane separating the nurse-cell from the oocyte has broken and nurse-cell Golgi bodies are inflowing into the oocyte.
- Fig 8. An egg-follicle showing the infiltration of nurse-cell Golgi bodies into the oocyte. The nurse-cell membranes separating the oocyte from them are intact. Ludford.
- Fig 9. A part of the same enlarged.
- Fig. 10 Shows infiltration of follicular Golgi bodies into the oocyte. Distinct follicular cell walls are present. Ludford.
- Fig 11 A fairly advanced egg-follicle A nurse-cell membrane separating the nurse-cell from the oocyte has broken down and the nurse-cell cytoplasm with its Golgi granules inflows into the oocyte. The oocyte cytoplasm is studded with yolk bodies and a vitelline membrane has been secreted between the follicular epithelium and the oocyte periphery. Mann-Kopsch
- Fig 12 End chamber showing the follicular epithelial cell and nurse-cells No mitochondria are found; F W. A Iron-alum hæmatoxylin.
- Fig 13 A young egg-follicle showing follicular nuclei, nurse cell nuclei, and mitochondria F. W. A. Acid Fuchsin
- Fig 14 A young egg-follicle with the naked follicular cell nuclei at the periphery The oocyte nucleus has differentiated and a number of mitochondria are present. A dense cytoplasmic zone surrounds the nucleus. The nurse-cell nuclear

membranes are indented by nucleolar granules F W A Champy-Kull stain

- Fig 15 Part of an egg-follicle The follicular cell walls are not yet visible and the oocyte mitochondria are transforming into albuminous yolk. F W. A. Champy-Kull stain
- Fig. 16 An egg-follicle showing the infiltration of the nurse-cell mitochondria into the oocyte The oocyte nucleolus is budding and some particles of it have been extruded into the cytoplasm The nurse-cells and oocytes are completely partitioned Champy stained with acid fuchsin and methyl green.
- Fig 17. Part of an egg-follicle showing nucleolar extrusion Champy stained with acid fuchsin and methyl green
- Fig. 18 Part of an oocyte showing the darkening of some follicular cells and a non-cellular patch Champy iron-alum hæmatoxylin
- Fig. 19 Part of an egg-follicle showing follicular non-cellular patches filled with dark grains. Vitelline membrane has begun forming at places Champy iron-alum hæmatoxylin.
- Fig 20. Part of an egg-follicle. The section passes through the nurse-cell region Extrusion of nurse-cell nucleoli is shown and a few accessory nuclei have been formed F. W. A Champy-Kull staining
- Fig. 21 The nurse-cell region of an egg-follicle The nurse-cells are filled with mitochondria The accessory nuclei are shown at the centre. The follicular epithelial cells are dwindling in the anterior region F W A iron-alum hæmatoxylin
- Fig 22 Part of an advance egg The membrane separating the oocyte from the nurse-cell has broken down and the nurse-cell cytoplasm with its mitochondria is streaming into the oocyte The accessory nuclei are enclosed by a separate membrane and are resting on the border of the oocyte Champy acid fuchsin and methyl green stain.
- Fig 23 A part of the chorion membrane F W A champy-kull-stain.

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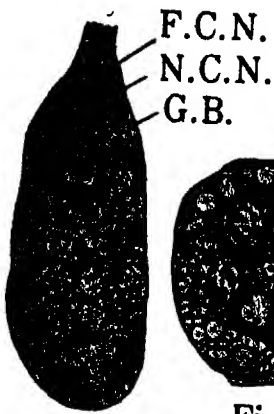


Fig. 1

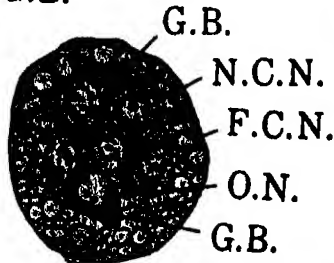


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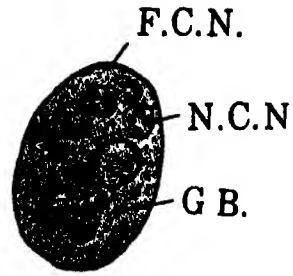


Fig. 5

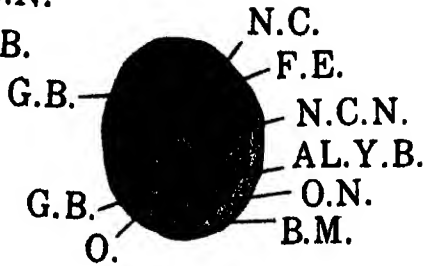


Fig. 6

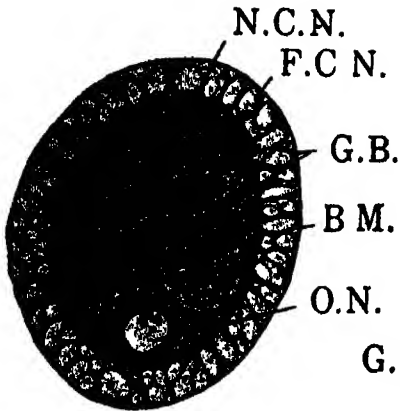


Fig. 3

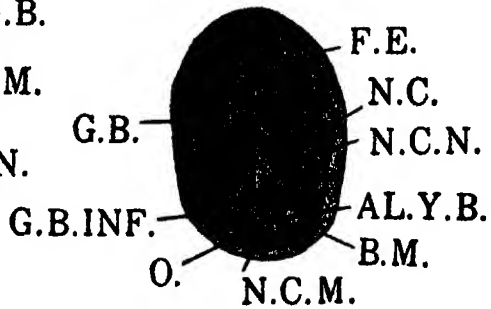


Fig. 7

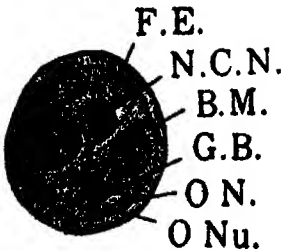


Fig. 4

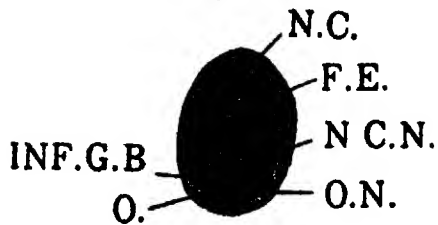


Fig. 8

•5 m.m.  
Figs. 4, 6, 7, 8.  
•1 m.m.  
Figs. 1, 2, 3, 5.

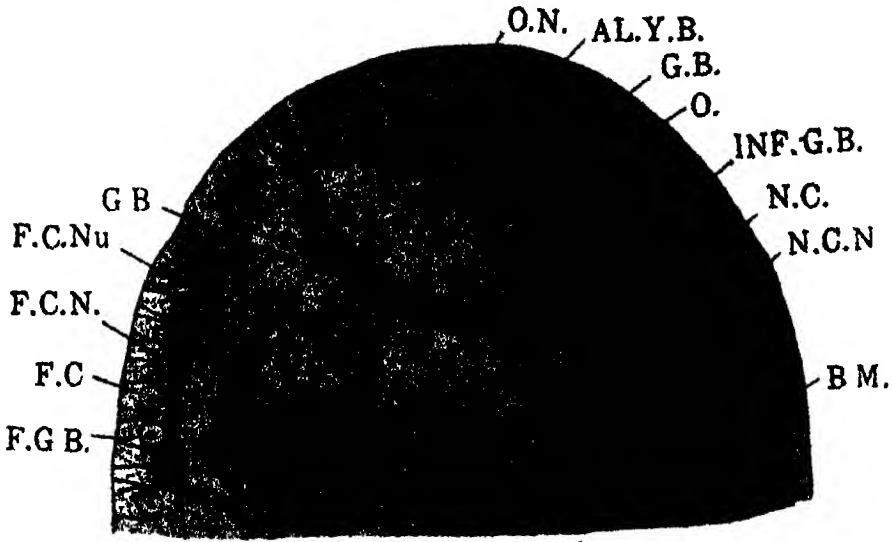


Fig. 9 F.C.Nu F.C.N. F.C. B.M.

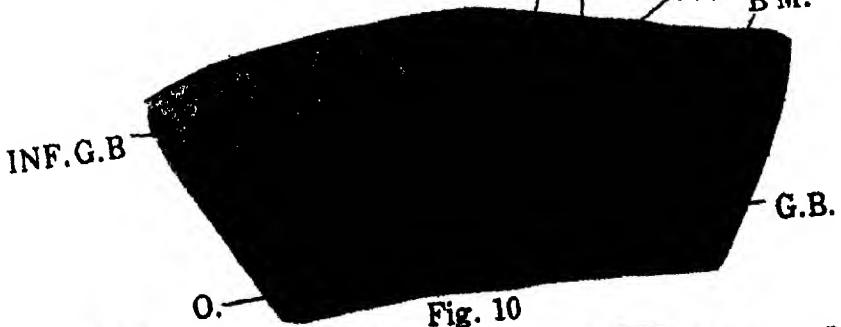


Fig. 10



Fig. 11



Fig. 12

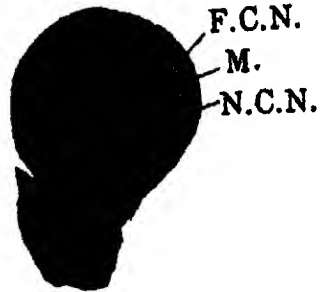


Fig. 13

1 m.m.  
Figs. 9, 10, 12, 13,

5 m.m.  
Fig. 11.

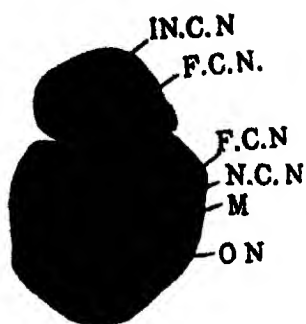


Fig. 14

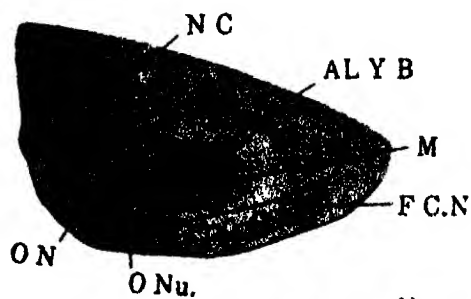


Fig 15

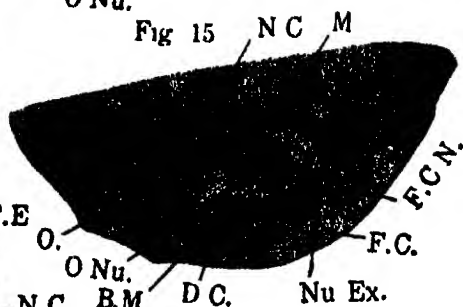


Fig. 17

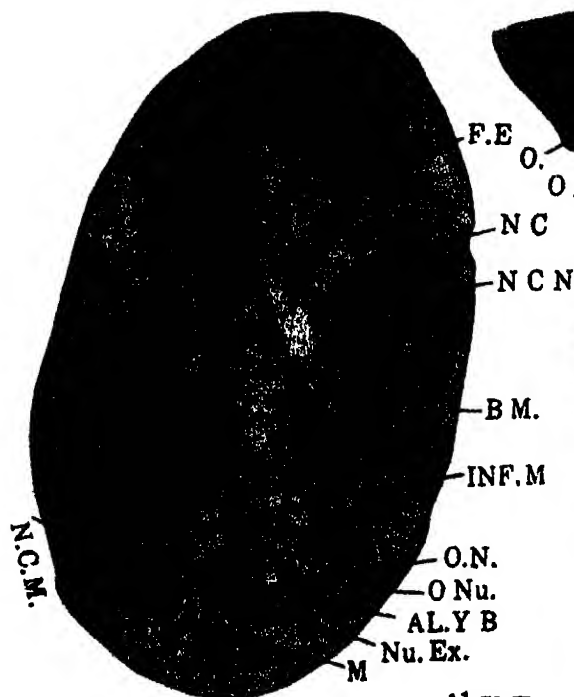


Fig 16

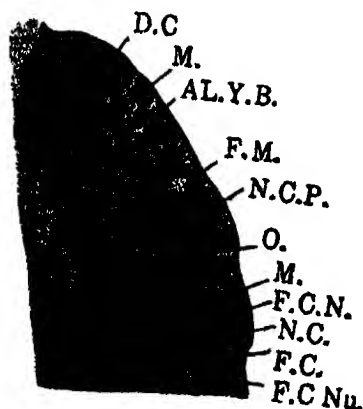


Fig 18

0.1 mm  
Figs. 14, 15, 16, 17, 18.

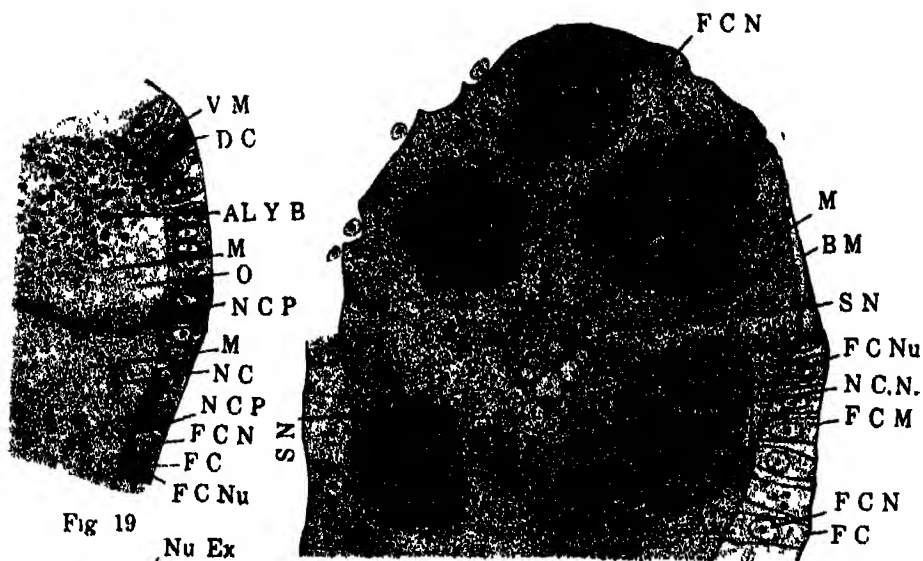


Fig 19

Fig 21

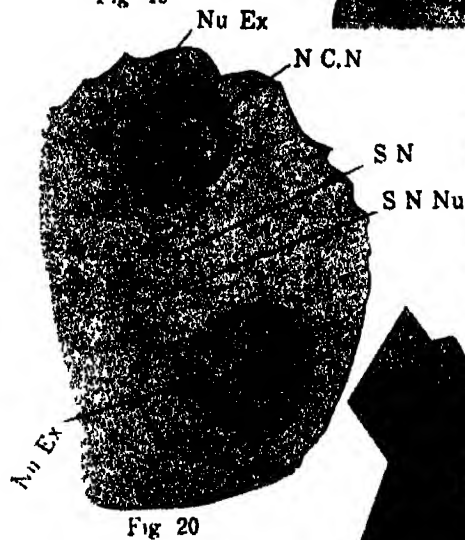


Fig 20

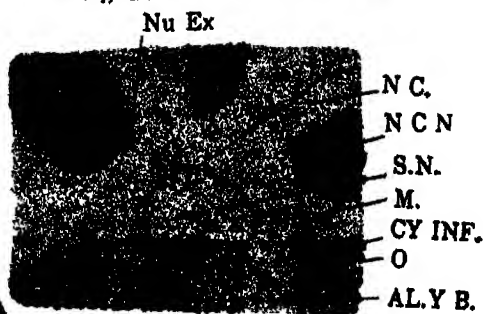


Fig 22



Fig. 23

1 mm  
Figs 19, 20, 21, 22, 23.



## NOTE ON THE ABSORPTION SPECTRUM OF CARBON DISULPHIDE

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The absorption spectrum of the vapour of carbon disulphide has received considerable attention by a number of workers and especially by Henri and his co-workers<sup>1</sup> who find two points of predissociation one at about 2820 Å U, the other at about 2000 Å U. These points of predissociation represent an energy of about 102 K cal/mol and 142 K cal/mol respectively. Henri interprets the first point of predissociation as the decomposition of the molecules into CS+S in its normal <sup>3</sup>P level and the second one as the decomposition into CS and an excited S atom in the <sup>1</sup>D term. The difference of about 40,000 cal/mol or 1.7 volts however is not in very good agreement with the energy of excitation for the <sup>1</sup>D state of sulphur which has been measured recently by Ruedy<sup>2</sup>, *viz.* 1.14 volts. From thermochemical data Henri calculates for the decomposition of the

molecule of gaseous  $\text{CS}_2$  into its three constituent atoms, an energy of 255.5 K cal/mol using a value of 141 K cal/mol for the sublimation of carbon. On the other hand linear extrapolation of the vibrational levels of the ground term  $^1\Sigma$  of the molecule CS as measured by Jevons<sup>8</sup> yields a heat of dissociation of 8.4 volts or 193 K cal/mol. As the sum 193 K cal + 102 K cal = 295 K cal is considerably higher than the 255.5 K cal obtained from thermochemical data, Henri concludes that the  $^1\Sigma$  term of the molecule CS dissociates adiabatically into normal C and excited S in the  $^1D$  state.

This conclusion however is not possible, not only because it is difficult to believe that the ground level of CS shall behave differently from that of CO, but also because, as we know to-day the combination of an atom in  $^1D$  with another one in  $^3P$  will not result in a  $^1\Sigma$  level of the molecule. Since all spin vectors are counterbalanced already in the singlet state of sulphur, there are no free vectors left which could neutralise those of the triplet term of carbon, to yield a singlet term of the CS molecule. We have therefore measured the absorption spectrum of  $\text{CS}_2$  vapour again. The vapour was contained in a quartz tube so that the temperature and pressure could be regulated. As the source of continuous light we used the Hydrogen tube. The spectra were taken with a Hilger I32 and a quartz spectrograph of the Littrow-type constructed by Messrs C. Leiss. The latter was used with one quartz prism only and gives a dispersion of about 10 Å U/mm at about 3200 Å U.



Fig. 1

Fig. 1 is a reproduction of the absorption spectrum in the near ultra-violet (temp. 30°C, pressure 1.5 cm in a 10 cm long tube of 1.5 cm cross section) in its natural size and Fig. 2 is the photometric curve obtained from it. The point of predissociation lies at 2965 Å U, equivalent to an energy of 4.16 volts or 96.1 K cal/mol. Similarly we obtain for the second absorption system, predissociation at 2160 Å U representing an energy of 5.71 volts or 131.9 K cal/mol. These values are slightly different from those of Henri. But such discrepancies are inevitable in measurements of predissociation data. Here predissociations result from perturbations of the vibrational levels by repulsive curves and such perturbations,

as is well-known, occur within rather wide limits. The successive vibrational levels of the  $\text{CS}_2$  molecule being themselves relatively not



— 2961.2  
— 2965 Pre-  
dissociation

Fig. 2

widely spaced, the observed predissociation is susceptible to changes in the conditions of temperature and pressure.

The CS bands have been recently remeasured<sup>4</sup> and the fine structure analysed, the heat of dissociation in the ground state being calculated as 7.75 volts or 179 K cal/mol. On adding to this the energy of the first point of predissociation, we obtain 275.1 K cal/mol as the optically found value for the heat of formation of gaseous  $\text{CS}_2$  from the atoms. In the thermochemical calculation of this value we do not use 141 K cal/mol for the sublimation of carbon which is certainly too low. 150 K cal/mol seems to be more reliable while from the optical data of the spectrum of  $\text{CO}$ <sup>5</sup> we obtain a still higher value of about 156 K cal/mol. So, we calculate the thermochemical value of the decomposition of  $\text{CS}_2$  as between 265 and 271 K cal/mol. This value is near enough to that obtained optically by the predissociation data. So, the first point of predissociation may be interpreted as a decomposition of  $\text{CS}_2$  into  $\text{CS}$  (ground  $^1\Sigma$ ) +  $\text{S}$  (ground  $^3P$ ). This is now in agreement with the fact that  $\text{CS}$  in the ground  $^1\Sigma$  state dissociates into two unexcited atoms. The energy difference between the first and second point of predissociation obtained by us is 1.55 volts. This is also not in agreement with the energy of excitation of the sulphur atom to its  $^1D$  term which has been determined to be 1.14 volts. But a complete agreement would be possible only if both repulsive curves to which the two predissociations are due, run completely parallel.

Since this case cannot be expected, and since the CS molecule cannot have an electronic level so near to its ground term (as can be seen from CO), the second point of predissociation has to be interpreted as a decomposition of CS<sub>2</sub> into CS (ground <sup>1</sup>Σ) and S (<sup>1</sup>D), in agreement with Henri's conclusions

### *References*

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# PROCEEDINGS OF THE ACADEMY OF SCIENCES

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## ON A FORMULA FOR $\pi_v(x)$

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Let  $\pi_v(x)$  denote the number of numbers, not exceeding  $x$  and which have just  $v$  different prime factors, and  $\sigma_v(x)$  the number of numbers not exceeding  $x$  which have  $v$  prime factors, multiple prime factors being counted multiply.

Landau<sup>1</sup> has shewn that\*

$$\pi_v(x) \sim \sigma_v(x) \sim \frac{1}{(v-1)!} \frac{x (l(x))^{v-1}}{\log x}$$

for every fixed value of  $v$

I prove here that†

$$\pi_v(x) = \frac{1}{(v-1)!} \frac{x (l(x))^{v-1}}{\log x} + \frac{B}{(v-2)!} \frac{x (l(x))^{v-2}}{\log x} + o\left(\frac{x (l(x))^{v-2}}{\log x}\right) \dots (1)$$

We write  $l(x)$  for  $\log \log x$

† An empty product (0!) is to be replaced by unity in (1), (2) and throughout the paper.

$$\sigma_v(x) = \frac{1}{(v-1)!} \frac{x(lx)^{v-1}}{\log x} + \frac{B}{(v-2)!} \frac{x(lx)^{v-2}}{\log x} + o\left(\frac{x(lx)^{v-2}}{\log x}\right) \quad \dots (2)$$

for every fixed value of  $v \geq 2$

§1

I have proved<sup>\*</sup> that

$$\pi_2(x) = \frac{x \log x}{\log x} + \frac{Bx}{\log x} + o\left(\frac{x}{\log x}\right) \quad (3)$$

where  $B$  is a constant<sup>\*</sup>. Hence (1)† is true for  $v=2$

Lemma 1

$$(a) \sum_{p \leq x} \frac{\log^r p}{p} = \frac{1}{r} \log^r x + E_r + O\left(\frac{1}{\log^q x}\right)$$

( $r \geq 1$ )  $E_r$  is a constant and  $q$  is any fixed integer

$$(b) \sum_{p \leq x} \frac{1}{p} = \log x + B + O\left(\frac{1}{\log^q x}\right)$$

Proof—See *Handbuch*, pp 201-203

Lemma 2

$$\sum_{p < \sqrt{x}} \frac{1}{p(\log x - \log p)} = \frac{\log x}{\log x} + \frac{B}{\log x} + \frac{E_1}{\log^2 x} + \dots + \frac{E_{n-1}}{\log^n x} + O\left(\frac{1}{\log^{n+1} x}\right)$$

where  $n$  is any fixed integer

Proof

$$\begin{aligned} \frac{1}{p(\log x - \log p)} &= \frac{1}{p \log x} + \frac{1}{\log^2 x} \frac{\log p}{p} + \dots + \frac{1}{\log^n x} \frac{\log^{n-1} p}{p} + \frac{\log^n p}{\log^n x} \frac{1}{p(\log x - \log p)} \\ \sum_{p < \sqrt{x}} \frac{1}{p(\log x - \log p)} &= \frac{1}{\log x} \left\{ \log x - \log 2 + B + O\left(\frac{1}{\log^q x}\right) \right\} \end{aligned}$$

$$^* B = \lim_{x \rightarrow \infty} \left\{ \sum_{p \leq x} \frac{1}{p} - \log \log x \right\}$$

† Since  $\sigma_v(x) = \pi_2(x) + \sigma(\sqrt{x})$ , (2) is also true for  $v=2$

$$\begin{aligned}
& + \sum_{p < \sqrt{x}} \frac{1}{\log^n x} \left\{ \frac{\log^{n-1} x}{(n-1) 2^{n-1}} + E_{n-1} + O\left(\frac{1}{\log^q x}\right) \right\} \\
& + \sum_{p < \sqrt{x}} \frac{\log^n p}{p \log^n x (\log x - \log p)} \\
& = \frac{1}{\log x} \left\{ Hx + B - \log 2 + \sum_{k=1}^{n-1} \frac{1}{k 2^k} \right\} + O\left(\frac{1}{\log^{q+1} x}\right) \\
& + R + \sum_{k=1}^{n-1} \frac{E_k}{\log^{k+1} x}
\end{aligned}$$

$$\text{where } R = \sum_{p < \sqrt{x}} \frac{\log^n p}{p \log^n x (\log x - \log p)}$$

$$\begin{aligned}
\text{Consider } S &= \sum_{p < \sqrt{x}} \frac{\log^N p}{p (\log x - \log p) \log^{N-1} x} \\
&= \sum_{\frac{1}{2}}^{\lfloor \sqrt{x} \rfloor} \frac{I(n) - I(n-1)}{\log n} \frac{\log^N n}{n (\log x - \log n) \log^{N-1} x}
\end{aligned}$$

$$\text{where } I(n) = \sum_{p \leq n} \log p = n + n \varepsilon(n) = n + O(ne^{-a\sqrt{\log n}})$$

where  $a > 0$

$$\begin{aligned}
S &= \sum_2^{\lfloor \sqrt{x} \rfloor} \frac{\log^{N-1} n}{n (\log x - \log n) \log^{N-1} x} \\
&+ \sum_2^{\lfloor \sqrt{x} \rfloor} \frac{n \varepsilon(n) - (n-1) \varepsilon(n-1)}{\log n} \frac{\log^N n}{n (\log x - \log n) \log^{N-1} x} \\
&= \Sigma_1 + \Sigma_2 \\
\Sigma_1 &= \sum_2^{\lfloor e^{N-1} \rfloor} \frac{\lfloor \sqrt{x} \rfloor}{\lfloor e^{N-1} \rfloor + 1} \\
&= O\left(\frac{1}{\log^N x}\right) + \int_{\lfloor e^{N-1} \rfloor + 1}^{\lfloor \sqrt{x} \rfloor} \frac{\log^{N-1} u}{u (\log x - \log u) \log^{N-1} x} du \\
&= O\left(\frac{1}{\log^N x}\right) + I(\lfloor e^{N-1} \rfloor + 1, \lfloor \sqrt{x} \rfloor) \\
&= O\left(\frac{1}{\log^N x}\right) + I(2, \sqrt{x}) - I(2, \lfloor e^{N-1} \rfloor + 1) - I(\lfloor \sqrt{x} \rfloor, \sqrt{x})
\end{aligned}$$

$$= O\left(\frac{1}{\log^N x}\right) + I(2, \sqrt{x})$$

since the last two integrals are of  $O\left(\frac{1}{\log^N x}\right)$

$$\text{Now } I(2, \sqrt{x}) = \int_{\log 2}^{\frac{1}{2} \log x} \frac{y^{N-1} dy}{\log^{N-1} x \cdot (\log x - y)} = \frac{1}{\log^{N-1} x} J_{N-1}$$

where  $J_{N-1}$  satisfies the relation

$$J_{N-1} = \log x J_{N-2} - \frac{1}{N-1} \left\{ \frac{1}{2^{N-1}} (\log x)^{N-1} - (\log 2)^{N-1} \right\}$$

$$\text{and } J_1 = \log x (\log 2 - \frac{1}{2}) + \log x \cdot \log \left(1 - \frac{\log 2}{\log x}\right) + \log 2$$

$$\therefore J_{N-1} = \log^{N-1} x \left\{ \log 2 - 1 + \frac{1}{3} - \sum_{k=3}^{N-1} \frac{1}{k 2^k} \right\} + O\left(\frac{1}{\log x}\right)$$

$$\therefore \Sigma_1 = \log 2 - 1 + \frac{1}{3} - \sum_{k=3}^{N-1} \frac{1}{k 2^k} + O\left(\frac{1}{\log^N x}\right)$$

$$\begin{aligned} \text{Also } \Sigma_2 &= \sum_2^{\lfloor \sqrt{x} \rfloor} \frac{n \varepsilon(n) \log^{N-1} n}{n (\log x - \log n) \log^{N-1} x} \\ &\quad - \sum_2^{\lfloor \sqrt{x} \rfloor} \frac{n \varepsilon(n) \log^{N-1} (n+1)}{(n+1) [\log x - \log (n+1)] \log^{N-1} x} \\ &\quad - \frac{\varepsilon(1) \log^{N-1} 2}{2 (\log x - \log 2) \log^{N-1} x} \\ &\quad + \frac{[\sqrt{x}] \varepsilon([\sqrt{x}]) \log^{N-1} ([\sqrt{x}] + 1)}{([\sqrt{x}] + 1) \{\log x - \log ([\sqrt{x}] + 1)\} \log^{N-1} x} \\ &= \sum_2^{\lfloor \sqrt{x} \rfloor} \frac{n \varepsilon(n)}{\log^{N-1} x} \left\{ \frac{\log^{N-1} x}{n (\log x - \log n)} \right. \\ &\quad \left. - \frac{\log^{N-1} (n+1)}{(n+1) [\log x - \log (n+1)]} \right\} + O\left(\frac{1}{\log^N x}\right) \\ &= \Sigma_2 + O\left(\frac{1}{\log^N x}\right) \end{aligned}$$



Now

$$\begin{aligned}
 \Sigma_3 &= \sum_2^{\lfloor \sqrt{x} \rfloor} \frac{n \varepsilon(n)}{\log^{N-1} x} \\
 &= \frac{1}{\log^{N-1} x} \sum_2^{\lfloor \sqrt{x} \rfloor} \frac{n \varepsilon(n)}{n(n+1)} \frac{\{(n+1) \log^{N-1} n - n \log^{N-1} (n+1)\} + O(\log^{N-1} n)}{(\log x - \log n) \{\log x - \log (n+1)\}} \\
 &+ \sum_2^{\lfloor \sqrt{x} \rfloor} O\left(\frac{n \varepsilon(n)}{\log^{N-1} x} \cdot \frac{\log^{N-1} n}{n^2 (\log x - \log n)^2}\right) \\
 &= \frac{1}{\log^{N-1} x} \sum_2^{\lfloor \sqrt{x} \rfloor} O\left(\frac{\log^{N-1} n}{\log x - \log n} \cdot \frac{\varepsilon(n)}{n}\right) + O\left(\frac{1}{\log^N x}\right) \\
 &= O\left(\frac{1}{\log^N x}\right) \\
 \Sigma_3 &= O\left(\frac{1}{\log^N x}\right)
 \end{aligned}$$

$$\text{Hence } S = \Sigma_1 + \Sigma_2 = \log 2 - 1 + \frac{1}{2} - \sum_3^{N-1} \frac{1}{k 2^k} + O\left(\frac{1}{\log^N x}\right)$$

$$R = \frac{1}{\log x} \left\{ \log 2 - 1 + \frac{1}{2} - \sum_3^{N-1} \frac{1}{k 2^k} \right\} + O\left(\frac{1}{\log^{N+1} x}\right)$$

$$\sum_{p < \sqrt{x}}^* p(\log x - \log p) = \frac{lx}{\log x} + \frac{B}{\log x} + \sum_1^{N-1} \frac{E_k}{\log^{k+1} x} + O\left(\frac{1}{\log^{N+1} x}\right)$$

Lemma 3.

For every fixed  $v \geq 2$

$$\begin{aligned}
 p \leq \frac{x}{2} \quad p \frac{1}{p} \frac{\{\log(\log x - \log p)\}^{v-1}}{\log x - \log p} \\
 = \left(1 + \frac{1}{v}\right) \frac{(lx)^v}{\log x} + \frac{B (lx)^{v-1}}{\log x} + o\left(\frac{(lx)^{v-1}}{\log x}\right)
 \end{aligned}$$

Proof

$$\sum_{p \leq \frac{x}{2}} \frac{1}{p} \frac{\{\log(\log x - \log p)\}^{v-1}}{\log x - \log p} = \sum_{p < \sqrt{x}} \frac{\Sigma_1}{\sqrt{x}} + \sum_{\sqrt{x} \leq p \leq \frac{x}{2}} \frac{\Sigma_2}{p}$$

\*  $q$  may be chosen  $\geq n$

Where

$$\begin{aligned}
 \Sigma_1 &= \sum_{p < \sqrt{x}} \frac{\{\log(\log x - \log p)\}^{v-1}}{p(\log x - \log p)} \\
 &= \sum_{p < \sqrt{x}} \left\{ (lx)^{v-1} + O\left(\frac{(lx)^{v-2} \log p}{\log x}\right) \right\} \frac{1}{p(\log x - \log p)} \\
 &= \frac{(lx)^{v-1}}{\log x} \{lx + B + o(1)\} + O\left(\frac{(lx)^{v-2}}{\log^2 x} \sum_{p < \sqrt{x}} \frac{\log p}{p}\right) \\
 &= \frac{(lx)^{v-1}}{\log x} (lx + B) + o\left(\frac{(lx)^{v-1}}{\log x}\right)
 \end{aligned}$$

Now

$$\begin{aligned}
 \Sigma_2 &= \sum_{\sqrt{x} \leq p \leq \frac{x}{2}} \frac{\{\log(\log x - \log p)\}^{v-1}}{p(\log x - \log p)} \\
 &= \sum_{[\sqrt{x}]}^{[x/2]} \frac{1}{n \log n} \frac{\{\log(\log x - \log n)\}^{v-1}}{(\log x - \log n)} \\
 &\quad + \sum_{[\sqrt{x}]}^{[x/2]} \frac{n \varepsilon(n) - (n-1) \varepsilon(n-1)}{\log n} \left\{ \frac{\{\log(\log x - \log n)\}^{v-1}}{n(\log x - \log n)} \right\} \\
 &= \Sigma_3 + \Sigma_4
 \end{aligned}$$

$$\begin{aligned}
 \text{where } \Sigma_3 &= \sum_{[\sqrt{x}]}^{[x/2]} \frac{\{\log(\log x - \log n)\}^{v-1}}{n \log n (\log x - \log n)} \\
 &= \int_{\sqrt{x}}^{x/2} \frac{\{\log(\log x - \log u)\}^{v-1}}{u \log u (\log x - \log u)} du + O\left(\frac{1}{\log x}\right)
 \end{aligned}$$

by applying Euler Maclaurin sum formulæ.

$$\begin{aligned}
 \text{Further } \Sigma_4 &= \sum_{[\sqrt{x}]}^{[x/2]} \frac{n \varepsilon(n) - (n-1) \varepsilon(n-1)}{\log n} \left\{ \frac{\{\log(\log x - \log n)\}^{v-1}}{n(\log x - \log n)} \right\} \\
 &= \sum_{[\sqrt{x}]}^{[x/2]-1} n \varepsilon(n) \left[ \frac{\{\log(\log x - \log n)\}^{v-1}}{n \log n (\log x - \log n)} \right. \\
 &\quad \left. - \frac{\{\log[\log x - \log(n+1)]\}^{v-1}}{(n+1) \log(n+1) [\log x - \log(n+1)]} \right] \\
 &\quad + [x/2] \varepsilon([x/2]) \left[ \frac{1}{[x/2]} \frac{\{\log(\log x - \log [x/2])\}^{v-1}}{\log x - \log [x/2]} \frac{1}{\log [x/2]} \right]
 \end{aligned}$$

$$= \frac{\{(\sqrt{x})-1\} \varepsilon((\sqrt{x})-1)}{[\sqrt{x}] \log([\sqrt{x}])} \frac{\{\log(\log x - \log(\sqrt{x}))\}^{r-1}}{\log x - \log(\sqrt{x})}$$

$$= \Sigma_5 + \Sigma_6 - \Sigma_7$$

Then  $\Sigma_5 = O\left(\frac{1}{\log x}\right)$

$$\Sigma_7 = O\left(\frac{1}{\log x}\right)$$

$$|\Sigma_6| < K \sum_{[\sqrt{x}]}^{[x/2]-1} \frac{n}{\log^q n} \left| \frac{\left\{\log \log \frac{x}{n}\right\}^{r-1}}{n \log n \log\left(\frac{x}{n}\right)} - \frac{\left\{\log \log \frac{x}{n+1}\right\}^{r-1}}{(n+1) \log(n+1) \log\left(\frac{x}{n+1}\right)} \right|$$

$$= O\left((\log x)^{r-1} \sum_{[\sqrt{x}]}^{[x/2]-1} \frac{1}{n \log^q n}\right) = O\left(\frac{1}{\log x}\right)$$

$$\Sigma_2 = \int_{\sqrt{x}}^{x/2} \frac{\{\log(\log x - \log u)\}^{r-1}}{u \log u (\log x - \log u)} du + O\left(\frac{1}{\log x}\right)$$

$$= \int_{\log 2}^{\frac{\log x}{2}} \frac{dy (\log y)^{r-1}}{y (\log x - y)} + O\left(\frac{1}{\log x}\right)$$

$$= \frac{1}{\log x} \left[ \int_{\log 2}^{\frac{\log x}{2}} \frac{(\log y)^{r-1}}{y} dy + \int_{\log 2}^{\frac{\log x}{2}} \frac{(\log y)^{r-1}}{\log x - y} dy \right] + O\left(\frac{1}{\log x}\right)$$

$$= \frac{I_1 + I_2}{\log x} + O(1)$$

where  $I_1 = \int_{\log 2}^{\frac{\log x}{2}} \frac{(\log y)^{r-1}}{y} dy = \int_{\log 2}^{\log\left(\frac{\log x}{2}\right)} v^{r-1} dv$

$$= \frac{1}{v} (\log x)^r - \log 2 (\log x)^{r-1} + o\left((\log x)^{r-1}\right)$$

$$I_2 = \int_{\log 2}^{\frac{\log x}{2}} \frac{(\log y)^{r-1}}{\log x - y} dy = \int_{\frac{\log x}{2}}^{\log x - \log 2} \frac{\{\log(\log x - y)\}^{r-1}}{y} dy$$

$$= \int_{\frac{\log x}{2}}^{\log x - \log 2} \frac{dy}{y} \left\{ (\log x)^{r-1} + O\left((\log x)^{r-2} \frac{y}{\log x}\right) \right\}$$

$$= (\log x)^{r-1} \{\log(\log x - \log 2) - \log(\tfrac{1}{2} \log x)\} + O\left((\log x)^{r-2}\right)$$

$$\begin{aligned}
 &= \log 2 (lx)^{v-1} + o \left( (lx)^{v-1} \right) \\
 \Sigma_3^* &= \frac{1}{\log x} \left\{ \frac{1}{v} (lx)^v + o \left( (lx)^{v-1} \right) \right\} + O \left( \frac{1}{\log x} \right) \quad \dots (B) \\
 \Sigma_1 + \Sigma_3 &= \left( 1 + \frac{1}{v} \right) \frac{(lx)^v}{\log x} + \frac{B (lx)^{v-1}}{\log x} + o \left( \frac{(lx)^{v-1}}{\log x} \right)
 \end{aligned}$$

Lemma 4

$$\sum_{p \leq \frac{x}{2}} \frac{1}{p (\log x - \log p)} = \frac{2lx}{\log x} + O \left( \frac{1}{\log x} \right)$$

This follows from Lemma 2 and (B)

Assume now (1) to be true for  $v=n \geq 2$ . We prove it to be true for  $v=n+1$

We have

$$\pi_{n+1}(x) = \frac{1}{(n+1)!} \sum_{p \leq \frac{x}{2}} \pi_n \left( \frac{x}{p} \right) + o \left( x \frac{(lx)^{n-1}}{\log x} \right)^1$$

Further

$$\begin{aligned}
 \sum_{p \leq x/2} \pi_n \left( \frac{x}{p} \right) &= \frac{x}{(n-1)!} \sum_{p \leq x/2} \frac{1}{p} \frac{\{\log(\log x - \log p)\}^{n-1}}{\log x - \log p} \\
 &+ \frac{Bx}{(n-2)!} \sum_{p \leq x/2} \frac{1}{p} \frac{\{\log(\log x - \log p)\}^{n-2}}{\log x - \log p} \\
 &+ x \sum_{p \leq x/2} a \left( \frac{x}{p} \right) \frac{1}{p} \frac{\{\log(\log x - \log p)\}^{n-1}}{\log x - \log p} \\
 &= \frac{x}{(n-1)!} \Sigma_1 + \frac{Bx}{(n-2)!} \Sigma_2 + x \Sigma_3 \text{ (say)}
 \end{aligned}$$

where  $\left| a \left( \frac{x}{p} \right) \right| < \varepsilon$  if  $\frac{x}{p} \geq x_0 = x_0(\varepsilon) \geq 3$

$$\begin{aligned}
 \text{Now } \Sigma_3 &= \sum_{p \leq \frac{x}{x_0}} + \sum_{\frac{x}{x_0} < p \leq \frac{x}{2}} \\
 |\Sigma_4| &< \varepsilon \sum_{p \leq \frac{x}{x_0}} \frac{1}{p} \frac{\left\{ \log \log \left( \frac{x}{p} \right) \right\}^{n-2}}{\log x - \log p}
 \end{aligned}$$

<sup>1</sup>This result is true when  $v=1$ .

$$< K_1 \varepsilon \frac{(lx)^{n-1}}{\log x}, \text{ and by lemma 4 if } n = 2$$

$$|\Sigma_5| = \left| \sum_{\frac{x}{x_0} < p \leq \frac{x}{2}} a\left(\frac{x}{p}\right) \frac{1}{p} \left\{ \frac{\log \log \left(\frac{x}{p}\right)}{\log x - \log p} \right\}^{n-2} \right|$$

$$< K_2 \sum_{\frac{x}{x_0} < p \leq \frac{x}{2}} \frac{1}{p} \left\{ \frac{\log \log \left(\frac{x}{p}\right)}{\log x - \log p} \right\}^{n-2}$$

$$< \frac{K_2}{\log 2} (lx_0)^{n-2} \sum_{\frac{x}{x_0} < p \leq \frac{x}{2}} \frac{1}{p} < K_3 \frac{(lx_0)^{n-1}}{\log x}$$

$$\Sigma_5 = \Sigma_4 + \Sigma_5 = o\left(\frac{(lx)^{n-1}}{\log x}\right)$$

$$\begin{aligned} \sum_{p \leq \frac{x}{2}} \pi_n\left(\frac{x}{p}\right) &= \frac{x}{(n-1)!} \left\{ \left(1 + \frac{1}{n}\right) \frac{(lx)^n}{\log x} + B \frac{(lx)^{n-1}}{\log x} + o\left(\frac{(lx)^{n-1}}{\log x}\right) \right\} \\ &\quad + \frac{B_2}{(n-2)!} \left\{ \frac{n}{n-1} \frac{(lx)^{n-1}}{\log x} + o\left(\frac{(lx)^{n-2}}{\log x}\right) \right\} \\ &\quad + o\left(\frac{x(lx)^{n-1}}{\log x}\right) \end{aligned}$$

$$= (n+1) \left[ \frac{1}{n!} \frac{x(lx)^n}{\log x} + \frac{B}{(n-1)!} \frac{x(lx)^{n-1}}{\log x} + o\left(\frac{x(lx)^{n-1}}{\log x}\right) \right]$$

$$\pi_{n+1}(x) = \frac{1}{n!} \frac{x(lx)^n}{\log x} + \frac{B}{(n-1)!} \frac{x(lx)^{n-1}}{\log x} + o\left(\frac{x(lx)^{n-1}}{\log x}\right)$$

which proves (1) for  $v = n + 1$ . Hence (1) is proved

To prove (2) we note that, if  $n \geq 3$

$$0 \leq \sigma_n(x) - \pi_n(x)$$

$$\leq \rho_1(x) + \rho_{n-2}(x) + A_{n-1}(x)$$

where  $\rho_v(x)$  denotes the number of integers, not exceeding  $x$  which have  $v$  different prime factors,  
and

$$A_{n-1}(x) = \sum_{p_1, p_2, \dots, p_{n-1} \leq x} 1 \quad \left( p_1 \geq p_2 \geq p_3 \geq \dots \geq p_{n-1} \right)$$

$$\begin{aligned}
 &= O \left[ \sum_{p \leq \sqrt{\frac{x}{2}}} \pi_{n-2} \left( \frac{x}{p^2} \right) \right] \\
 &= O \left[ \sum_{p \leq \sqrt{\frac{x}{2}}} \pi_{n-2} \left( \frac{1}{p^2} \right) \right] \\
 &= O \left[ \sum_{p \leq \sqrt{\frac{x}{2}}} \frac{x}{p^2} \frac{\left( \log \log \frac{x}{p^2} \right)^{n-3}}{\log x - 2 \log p} \right]
 \end{aligned}$$

$$\begin{aligned}
 \text{But } \sum_{p \leq \sqrt{\frac{x}{2}}} \frac{1}{p^2} \frac{\left( \log \log \frac{x}{p^2} \right)^{n-3}}{\log x - 2 \log p} &= \sum_{p \leq x^{\frac{1}{2}}} + \sum_{x^{\frac{1}{2}} < p \leq \sqrt{\frac{x}{2}}} \\
 &= o \left( \frac{(lx)^{n-2}}{\log x} \right) + O \left( \frac{(lx)^{n-3}}{x^{\frac{1}{2}}} \right) \\
 A_{n-1}(x) &= o \left( \frac{(lx)^{n-2}}{\log x} \right)
 \end{aligned}$$

$$\text{Further } \rho_v(x) \sim \frac{1}{(v-1)!} \frac{x(lx)^{v-1}}{\log x}$$

$$0 \leq \sigma_n(x) - \pi_n(x) = o \left( \frac{x(lx)^{n-2}}{\log x} \right) \quad (4)$$

From (1) and (4) we get (2) if  $v \geq 3$ . We have already seen that (2) is true if  $v=2$ . Hence (2) is proved for  $v \geq 2$ .

### References

- 1 Landau, *Handbuch*, pp 205—213
- 2 Shah, *Bombay University J.*, Vol 2, Part II, pp 35—39

# THE MATHEMATICAL THEORY OF A NEW RELATIVITY

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## INTRODUCTION

In Chapter III\* the existing theories about the expansion of the Universe have been, for economy of space, very briefly criticised, and it is submitted that extraordinary assumptions are made in these and that they are also wholly inadequate. The impossibility of a cosmical force of repulsion, acting at a distance, and increasing with the distance between two bodies, has been pointed out. It has also been shown that the Rotational Theory of Light, published in 1933 to reconcile the phenomena of interference, diffraction and scintillation, can partially explain the recessional velocities of nebulae. This assumption is not essential for the main theory, but its purpose is merely to show that the apparent recessional velocities are in part spurious, and that the huge mass of a distant nebula like the one in Ursa Majoris is not running away from us at anything like 30,000 kms per second.

In Chapter IV a natural assumption has been made that emanations from particles of matter are not confined to our present range of observation, but that corpuscles called gravitons, finer than light corpuscles, are also emitted, though they are beyond our vision. But even this assumption is not essential for the theory. As shown in Section V, one may start simply with the known fact that light radiations, *i.e.*, swarms of light corpuscles or radions, emanate from every part of an outer shell of a luminous body. The assumption made by Einstein and de Sitter that the velocity of light in space is constant is accepted as a first approximation. But their further assumption that the velocity of light relative to two moving bodies is always the same, no matter with what

\* The first two chapters of this paper were printed in the Proceedings of the Academy of Sciences, U.P., India, Vol. 4, Part 1, pp 1—36 (August, 1934) and dealt with the law of gravitation.

different velocities they may be moving, has been rejected, and the obvious assumption is made that the velocity of light relative to the front part of a moving body is different from that relative to its rear when light moves in opposite directions. From this simple fact the acceleration of a moving body which is emanating matter is deduced dynamically, furnishing a correction to Newtonian mechanics. The cosmological principle in Relativity that the picture of the Universe is exactly the same no matter from what point we observe it has been rejected. The apparent effect that all distant nebulae seem to be moving away from the earth is explained on the simple principle of components of accelerations and velocities. The Universe need no longer be scattering away, due to any supposed explosion from a condensed spherical shell which suddenly burst ages ago.

In Chapter V the assumption in Special Relativity that light from one moving body to another moving body takes the same time as light from the second body to the first, no matter how different their velocities may be, as well as the definition of common time between two bodies determined by a single journey of light are not accepted. Common time is defined as the whole time taken by light from one body to the other in performing the double journey. It is shown dynamically that both bodies, employing such a messenger, measure the common time as well as the relative distance between them exactly alike. The velocity of light is shown not to be absolute, but only the average velocity of light in a to-and-fro journey is nearly absolute. In view of the admitted fact that "All experimental methods of measuring the velocity of light determine only an average to-and-fro velocity" (Eddington<sup>1</sup>), it is wholly unnecessary to assume the absoluteness of a single journey velocity of light, and it is quite sufficient to accept that in a double journey the velocity is nearly absolute, and so no terrestrial experiment detects the motion of the earth, the error being of too small an order.

Newton's Mechanics was designed for an omniscient superman, who could see distant objects instantaneously, and measure time and space also instantaneously, which meant an employment of a messenger travelling with infinite velocity, so that simultaneous velocities and accelerations of several bodies could be ascertained at once. To Newton forces moved with infinite velocities and acted instantaneously, and so it made no difference whether the influenced body was stationary or was moving with a finite velocity. But a mere human being can employ only light as his fastest messenger, which travels with only finite velocity. And the forces which he experiences neither travel with infinite velocity



nor act instantaneously. Newton's Mechanics therefore requires a correction when applied to bodies moving with high velocities. Einstein gets over the difficulty by attributing to the velocity of light some of the properties of infinity, *e.g.*, of absoluteness and maximum speed, even though these necessitate contraction of length, extension of time and increase of mass with velocity, and involve a curvature of space, making the Universe finite and surprisingly small, and the space itself expanding into non-space.

As a substitute for Einstein's Relativity theory, only one single assumption, which is natural and should be obvious, is made that all influences take time to act and do not act instantaneously, which in dynamical language means that they are propagated with finite and not infinite velocities.

All terrestrial experiments involving the addition of velocities, like those of Hoek, Fresnel and Fizeau, are explained by the *first* necessary deduction that the relative velocity between two bodies moving with velocities  $v'$  and  $u$ , measured by employing a messenger travelling with velocity  $D$  in a to-and-fro journey, is different when both the bodies are moving than when one is reduced to rest, and is given by the formula

$$\frac{v}{v' - u} = \frac{1 + \frac{v'}{D} - \frac{u}{D}}{\left(1 + \frac{v'}{D}\right)\left(1 - \frac{u}{D}\right)} = \frac{1}{1 - \frac{v'u}{D^2}} \text{ nearly}$$

All astronomical observations, including the advance of the perihelia of planets, the deflection of light and the shift of the spectral lines (already explained in Chapters I and II) and all terrestrial experiments, like those of Michelson and Morley, Trouton and Noble, Kaufmann and Bucherer, are explained by the *second* necessary deduction that wherever there is a field of force which takes time to act and so can be represented by a velocity of flow  $D$ , no matter whether it be of gravitation or radiation, or electric or magnetic field, then its action on a body moving with velocity  $v$  inclined at an angle  $\theta$  to the direction of the flow, is exactly the same as if the body were stationary and the direction of the flow of the same magnitude were shifted forward by an angle  $\alpha$  given approximately by the ratio applicable to the compounding of the two velocities  $D \sin \alpha = v \sin \theta$ . So that when the angle is a right angle the effective force is decreased by the factor  $\cos \left( \sin^{-1} \frac{v}{D} \right) = \sqrt{1 - \frac{v^2}{D^2}}$ .

All the problems like Sommerfeld's fine structure of spectral lines are explained by the *third* necessary deduction that when a force travelling with a finite velocity  $D$  acts on a thin spherical shell of radius  $a$ ,

spinning with an angular velocity  $w$  round an axis through its centre perpendicular to the force, the effect is to decrease or increase its spin according as the force is repulsive or attractive, but always to decrease the component of the force along the diameter by the factor  $\sqrt{1 - \frac{a^2 w^2}{D^2}}$  nearly

With the help of these generalised laws, Galileo's and Newton's Mechanics, with proper corrections for moving bodies, is completely restored, and although Einstein's Theory of Relativity is not accepted, all its practical results are deduced in full

I must again express my gratitude to Dr D. S. Kothari, MSc, PhD, and Mr A. N. Chatterji, MSc, for their very kind help, similar to that given before

## CHAPTER III

### Anomalies in the Existing Hypotheses

#### SECTION I

#### THE EXPANDING UNIVERSE

1 *The Observed Facts*—Slipher discovered in 1912 (confirmed in 1922) that the spiral nebulae possess radial velocities, predominantly of recession, and large as compared with the ordinary range of stellar velocities. In 1929, Dr Hubble found that the velocity of recession was greater the greater the distance, and enunciated the law that the mean velocity of recession at a given distance is proportional to the distance. The observations show clearly that the radial velocities appear to obey a linear law of increase, the velocities being simply proportional to the distances. The individual recessional velocities do not obey the law accurately, but the deviations in radial velocity from the velocity distance proportionality are relatively small, perhaps of the order of 80 km. per sec. Another extraordinary observed fact is that all the galaxies seem almost without exception to be running away fast from our solar system. One nebula, forming a faint cluster in the constellation Gemini is found to be receding at a speed of 24,000 kms per second, i.e., about the speed of an alpha particle. Its distance is about 150 million light years. It is now reported that a nebula in Ursa Majoris is moving away with a velocity equal to about one-tenth of the velocity of light. Observations show that outside a sphere of a little over a million light years radius round our galaxy, 80 nebulae are observed to be moving outwards, and not one has been observed moving inwards. Out of 90 galaxies

which have been observed, only five are found to be moving towards our system, but even these five exceptions are confined to the very nearest of the nebulae and their velocities of approach are not large. Even after corrections for the motion of the Sun in its orbit round the centre of the galaxy have been made, the velocities of approach of the nearest nebulae are considerably reduced, but still they are not found to possess velocities of recession proportional to their distances. It is, however, believed that allowing for all possibilities of error and misinterpretation, there is a residual expansion, and the super-system of galaxies is dispersing as if it were a puff of smoke or as if a gas suddenly released would expand.

2. *The Inference*—As there is absolutely no reason why all the nebulae should be running away from the earth as the centre of expansion, the inference is a law of general uniform expansion, that is each individual body is receding from every other body at a rate proportional to the distance between them. The serious difficulty is that for a finite space this implies an explosion from a centre, and the particles must scatter away with velocities increasing at a rapidly progressive rate.

## SECTION II

### THE INADEQUACY OF CLASSICAL THEORIES

1. *Newton's Corpuscular Theory*—If light be regarded as a swarm of bullets travelling in straight lines through space, as Newton imagined, there would seem to be no reason why they should lose any part of their velocities or energy on the way, if Newton's first law of motion holds good. The only obstruction they can meet would be from material particles, which will either absorb them or scatter them, and not cause any change in frequency.

2. *Huygens' Wave Theory*—The wave theory of light also cannot explain how the ether waves can lose their energy partially in their passage through space. Waves do not obstruct each other, but pass through. The law of the conservation of energy is contrary to any such automatic loss.

3. *Planck's Quantum Theory*—The observed shifting of the spectrum of a nebula towards the red signifies lower frequency of light waves, which, according to the Quantum Theory, would mean lower energy, so that if for any cause a light quantum can lose some of its energy in travelling through space, the reddening would be accounted for, and the loss of energy would be proportional to the distance. But neither the wave theory nor the corpuscular nor the quantum theory has succeeded in explaining how such a loss can occur. As pointed out by

Eddington<sup>3</sup> "there is nothing in the existing theories of light (Wave Theory or Quantum Theory) which justifies the assumption of such a loss, (i.e., loss of energy proportional to distance)".

4 *Zwicky's Theory*—Zwicky suggested that light by its gravitational effects parts with its energy to the material particles thinly strewn in intergalactic space which it passes on its way. But the numerical result obtained after allowing for such gravitational effects showed that the theory was fallacious. The loss of energy due to gravitational effects would not be sufficient to account for the extent of the reddening observed. He has also suggested that the gravitational pull of stars and nebulae on light passing near them causes reddening, just as bending of starlight at an eclipse of the sun. But no adequate explanation has been given as to how the pull of stars can redden the light; it will merely deflect it.

5. *Macmillan's Suggestion*—Macmillan<sup>4</sup> suggested that the red shift may be due to the loss of energy in the photon in course of time, due either to inherent instability or collisions with other photons. One can heartily agree with his conclusion that "Such an interpretation of the extraordinary shifts that are observed will be more acceptable to many than an interpretation which makes our galaxy a centre from which all others are fleeing with speeds that are proportional to the distances". But unfortunately there is no explanation of any inherent instability in photons, and the straight collisions would scatter them away.

### SECTION III

#### RELATIVITY THEORY

1. *Einstein's Universe*—Einstein abolished infinity and modified his original equation so as to make space at infinite distances bend round itself and close up. The new equation  $G_{\mu\nu} = \lambda g_{\mu\nu}$  contains a cosmical constant. Two forces—the Newtonian attraction and the cosmical repulsion—oppose each other and create an Einstein's universe in unstable equilibrium. In order that a particle placed anywhere may remain at rest, Einstein's world has to be filled with rather too much matter having negligible velocity, and spread over uniformly through space. "This is like restoring a crudely material aether regulated however by the strict injunction that it must on no account perform any useful function, lest it upset the principle of relativity."<sup>5</sup> The

supposition is contrary to observation, as the universe we see has considerable matter moving with great velocity

2 *De Sitter's Universe* — De Sitter assumed the density of matter to be infinitely small so as to make the Newtonian attraction negligible, and cause the cosmical repulsion to produce an expansion. But in point of fact, even de Sitter's world requires a large quantity of matter forming a sort of mass-horizon. "He has merely swept the dust away into unobserved corners" "Einstein's universe contains matter, but no motion, and de Sitter's contains motion, but no matter." It is clear that the actual universe containing both matter and motion does not correspond exactly to either of these abstract models. When observed from inside, an empty or motionless universe simply does not exist.

3 *Lemaître's Solution* — Lemaître's theory is that the world began with a violent projection from the state in which it was condensed to a point or atom, and it has now got past the Einstein state. The supposition is that the density of the universe does not depend on position, but is uniform in space, though varies with time. The gravitational effect is taken as nil. The hypothesis involves the assumption of a neutral zone, materialised by a thin spherical shell of negligible mass and no interior stresses, separating altogether the matter inside the condensation from the matter outside, so that matter crossing the shell from outside or from inside is forced to rebound at its boundary. All particles outside the shell are endowed with a hyperbolic radial velocity of escape, while all the matter inside the shell has an elliptic radial velocity and so must fall back on the centre. It is hardly necessary to point out that such a bifurcation is extremely arbitrary.

4 *Eddington's Hypothesis* — Eddington<sup>7</sup> supposes that primordial material might have consisted of hydrogen (or free protons or electrons). The formation of condensation somehow had the start of the conversion of mass into radiation, thus the effect of conversion of radiation into material mass was to make the universe expand. If primordial material consisted of only matter and no radiation, then the conversion of mass into radiation would occur first, resulting in a contraction. In any case, Eddington's hypothesis is unable in itself to explain an expansion proportional to linear distance.

It has been suggested by A. C. Banerji<sup>8</sup> of Allahabad that the breaking-up of a photon into an electron and a positron, known as the process of *electrofission*, may explain why the Universe started expanding from the Einstein Universe. Starting with the relativity assumption that "mass for mass matter exerts less gravitational attraction than radiation," he

inferred that the conversion of radiation into matter will lessen the gravitational factor and so if by some method the photon breaks up into two material particles, the Einstein Universe will start expanding

5 The statement that mass for mass matter exerts less gravitational attraction than radiation is only true even in Relativity when the influence of matter on light passing transversely is concerned. Light itself is not known to exert any gravitational attraction on matter when passing by it. And light is also not at all known to have any gravitational interaction with itself. So if photons only existed, there would have been no gravitation; and if a photon can at all split up into two material particles they would bring into existence a gravitational force for the first time, which would counteract any expansive tendency. Electrofission could not therefore stimulate expansion, particularly as the condensation of radiation into matter would diminish pressure by reducing velocities. In Relativity "the effect of the gravitation of the sun on a light wave, or a very fast particle, proceeding radially is actually a *repulsion*."<sup>9</sup> Thus if for some reason condensations began to form, light waves would be repelled from such centres of condensation, resulting in some expansion. But this can be so only in a four-dimensional universe, while the motions of the nebulae which we actually observe are strictly three-dimensional.

#### SECTION IV

##### MILNE'S WORLD STRUCTURE

1 Milne<sup>10</sup> adopts Einstein's Special Theory of Relativity in its kinematical aspects, and assumes that two observers in uniform relative motion have identical views of the universe. The world is supposed to have originated with a swarm of particles moving in straight lines, each with a uniform velocity without collisions, possessing an entirely arbitrary velocity distribution. After lapse of sufficient time, the outward moving particles will move into the empty space outside an imaginary sphere, the faster will gain on the slower and the fastest moving will form an expanding spherical frontier zone followed by the next fastest. The inward moving particles will move inward, traverse a chord of the sphere, emerge at the other side and then move outwards.

(1) The theory ignores the effect of gravitational interaction altogether. (2) It evades the possibility of collisions. (3) It assumes that the position is identical, whether the point of observation is near the surface or near the centre. (4) It also assumes that sufficient time has

already elapsed for things to adjust themselves—a purely arbitrary assumption, as there is no reason why some slow particles should still not be moving from distant regions towards the centre, particularly if space is not finite (5) To provide distribution of nebulae up to 150 million light years, high speeds must be more frequent than low speeds— an anti-Maxvillion distribution of speeds in a compact aggregation of galaxies<sup>11</sup> (6) It starts with a swarm of particles moving in all directions without giving any explanation how they came to be so moving at the start (7) There is difficulty in supposing that the velocities would always be proportional to distance from the centre Two nebulae at different distances moving with nearly equal velocity towards the centre can never follow the proportionality of distance law measured from the centre, even though they have passed beyond it. (8) The mathematical equations yield the result  $dr/dt = r/t$ , which shows that the velocities vary with time and are different at different epochs This equation is not the same thing as  $dr/dt = kr$ , where  $k$  is a constant in time as well as in space (9) Milne's universe behaves as if the system was created at the natural origin of time  $t$  equal to zero, and the expansion is inevitable and an essential feature of evolution

2. In addition to the cosmological principle that all particles in the universe are equivalent in their relationship, the hydrodynamical equations of motion and continuity are employed<sup>12</sup> The universe is treated as if consisting of a huge mass of fluid with all the properties of a fluid including continuity and excluding the existence of singularities At every point, the motion is one of flow, without acceleration In contravention with the ordinary ideas of Newtonian gravitation, the nebulae can only be in uniform rectilinear motion, whatever their interaction, *i.e.*, whatever the law of gravitation Milne's solution is only the limiting case of the general relativity treatment of Einstein's field equations representing expanding universes, when the gravitational interaction of the particles tends to zero of the general relativity solution<sup>13</sup>

As the universe we see consists of vast condensations of matter and huge void spaces in between, hydrodynamical principles can hardly with any justification be applied to obtain a formula for expansion of any region when seen from inside, nor can the gravitational effect be properly ignored

Of course, if the visible region of the Universe, including our Galactic system and the observed nebulae, even when seen from inside, can be wrongly assumed to constitute a continuous fluid, then no elaborate mathematics is required for the conclusion that a general expansion must

obey the proportionality to distance law. If when any fluid is heated, every region of it expands and pushes out its neighbouring regions, then the whole expansion must follow that law, but not so if the heating is non-uniform.

## SECTION V

### THE IMPOSSIBILITY OF COSMICAL REPULSION

1. Apart from the extraordinary assumptions as to curvature of space, incomprehensible properties of the velocity of light, variability of time and mass with velocity and numerous other unconvincing results, Relativity leads inevitably to a cosmic force of repulsion, in addition to the apparent force of attraction. This inexplicable "cosmical repulsion" not only acts at a distance, but unintelligibly increases in intensity with the distance between two bodies. Such a concept is philosophically an impossible one. If one body were to influence another body, it is logical to assume that the influence would be greater when the distance between them is smaller. It is altogether illogical to suppose that their influence on each other is greater when the distance is greater.

2. The hypotheses necessarily involves a force of repulsion directly proportional to the distance from every-where. It is like a dispersing force so that the whole system is scattering away, each particle increasing its velocity rapidly. As Eddington puts it "repulsion has no centre, &  $\epsilon$ , every point is a centre of repulsion."

Einstein was himself doubtful as to the feasibility of introducing a cosmical repulsion, and considered it "theoretically unsatisfying." But it has now become an essential element not only in de Sitter's theory, but also in the theory propounded by Weyl.

3. If there were a general expansion of the universe then there is no reason why the stars should not recede from all the other stars at the same rate as explosion would be effective in all directions. We would then see not only stars receding from the earth, but also separating from each other, and thereby increasing the subtended angle on the earth. But in point of fact there is no such high transverse velocity observed between two stars. As every part of space is supposed to be expanding the inflation ought to affect distances between planets in the solar system, electrons in an atom, that is to say, atoms, human beings and every thing on the earth should expand at the same rate as the universe. The expansion might be small, but should exist, though in these cases they may not be observable.

But Eddington suggests that the inflation would be uniform only if the density is uniform, and concludes that only the intergalactic



distances expand, the galaxies themselves are unaffected and all lesser systems like star clusters, stars, human observers and their apparatus and atoms are entirely free from expansion

4 As in Relativity all change is relative, the expansion of the universe can with equal proportion be explained by a supposed shrinking of our material standards As Eddington<sup>14</sup> has put it "The theory of the expanding universe might also be called the theory of the shrinking atom We suppose that we are always the same and that our environment changes, but we ourselves may be shrinking"

5 The rule that the receding velocity of a spiral nebula is proportionate to its distance is not obeyed by every individual nebula Furthermore the observed velocities of the five nearest nebulae do not follow the linear law of increase strictly They have high velocities of approach, which can be reduced if the rotation of the galactic system is taken into account But no amount of corrections can convert their velocities to those of recession proportional to their distances These nebulae are exceptions to the supposed law of expansion, and even a solitary exception would destroy the law

6 When the Universe is observed from inside, *i.e.*, from the earth it is found to consist of large condensations of mass moving relatively to each other, and with vast empty spaces in between. When observed from inside, it is, therefore, impossible to accept Einstein's assumption that it is motionless, or de Sitter's assumption that it is empty, or Milne's supposition that it is continuous like a fluid

7 Relativity attempts to explain the expansion by the suppositions that space is curved and bends round itself, that the nebulae are all situated on an imaginary three dimensional skin of a four dimensional continuum, and that this unimaginable hollow sphere is expanding by an apparent cosmical force of repulsion increasing with the distance If the interaction of a hundred thousand million galaxies (nebulae) be also taken into account, then Relativity would require a space of four hundred thousand million minus four dimensions to explain the Universe!

## SECTION VI

### THE ROTATIONAL THEORY OF LIGHT

Although the classical and modern theories fail to explain how energy can be lost merely by passage through space, the Rotational Theory of Light put forward in Part II of my *Unified Theory of Physical Phenomena* (1933) can *partly* account for it.

1 First, if light consists of a swarm of particles, rotating with a period round the path of their forward motion, then while travelling forward their side collisions with other particles in space may, without substantially affecting their forward velocity, reduce their rotational velocity and so alter their frequency. If space is full of fine particles the frequency of light would be reduced in proportion to the distance travelled. The light would become proportionately redder. The more distant a nebula is the longer has light to travel from it, and the more it loses its rotational motion, and the more it becomes red. The loss of energy proportional to distance itself suggests that the change is in some way the result of passage through space. The apparent shift of light to the red side of the spectrum can be partly explained by the progressive loss of rotational motion or angular momentum of the radions. The forward velocity remains unaffected, because either radions collide and are scattered, or they pass through unobstructed, with diminished angular motion. The slight deflections nullify themselves on the average.

Compton has discovered that radiation is both deflected and reddened when it encounters electrons in space. In his experiment when X-rays encountered electrons, the spectral line suffered a shift towards the red, i.e., the wave length increased. "The impact reduces the rotational velocity, it increases the period and therefore  $\lambda$  the wave length, which is the longitudinal motion during the increased time, also increases. And so radiation gets reddened. A good part of the observed recession of the stars can be accounted for by the reddening of light as it travels through space"<sup>15</sup>

2 Secondly, observations may perhaps also confirm that the stars in such parts of the galactic system as contain more matter are redder than even more distant stars. Light from a number of globular clusters, at about equal distances from us, but so selected that the amount of intervening gravitational matter varied greatly was examined by P. ten Bruggencate and found to vary according to the intervening matter.<sup>16</sup> The pull of the stars and the nebulae on passing close to them would combine to increase the radius of the rotational motion, thus decreasing the frequency, but would cancel each other so far as the forward velocity is concerned. In this way also a good part of the reddening can be explained.

3. Thirdly, there can be an inherent loss of angular momentum by the radions in a beam of light colliding against each other while rotating. The loss of angular momentum would mean a decrease in angular velocity which in rotation would correspond to decrease in frequency.

Thus loss in frequency would be proportional to the whole time taken that is proportional to the distance travelled

4. In this way a very large part of the spectral shift may be the result of the rotation of the radions, and therefore, a greater part of the velocities of recession may be spurious

The loss in frequency due to these causes would be

$$-\Delta\nu = \nu - (\nu + \Delta\nu) = g r,$$

where  $r$  is the distance travelled by light and  $g$  is a constant. From this we get

$$\frac{c}{\lambda} - \frac{c}{\lambda + \Delta\lambda} = gr \quad \Delta\lambda = \frac{g}{c} \frac{\lambda^2}{1 - \frac{gr}{c}} \quad r = \frac{g\lambda^2}{c} \quad r \text{ nearly} \quad (181)$$

5. Whether light passing through intensely cold regions of space also automatically loses some energy can be tested by letting two beams of monochromatic light from one source pass through two separate and long vacuum chambers and then interfere, and observing the changes, if any, in the interference fringes when one chamber is heated and the other cooled.

For a detailed consideration of the Rotational Theory of Light, reference may be made to the Unified Theory of Physical Phenomena, Part II (1933)

## CHAPTER IV

### The Emission Theory of Matter

#### SECTION I

#### THE EMISSION THEORY OF GRAVITATION

In my Unified Theory of Physical Phenomena, published in 1933, I pointed out that action at a distance was illogical, and that the apparent force of attraction was nothing but motion caused by an internal action in matter. It was pointed out at some length that Newton's Law of Gravitation between two stationary bodies could be very easily deduced from the assumption that every particle of matter is emitting in all directions small corpuscles called "gravitons" and that the rate of emission depends on the material potential in its immediate neighbourhood, decreasing as the potential increases.

In the first two chapters of the present paper no physical hypothesis to explain the phenomenon of gravitation was adopted, the only solitary assumption made was that the gravitational effect is propagated with a finite velocity. As in Relativity nothing can exceed the velocity of light, the assumption was natural enough. All the equations and the

formulae were mere mathematical deductions by the application of the principle of the Doppler effect, the diminution of intensity with the inverse square of the distance and the shifting forward of the line of attraction in conformity with the principle of the aberration of light, when the two bodies, instead of being stationary, are in relative motion. In the present chapter, except Sec V, it is assumed that every particle of matter is emanating fine corpuscles called gravitons, smaller even than the light particles called radions. Cosmic radiations on the ultra violet side and the electro-magnetic waves on the infra red side are within the present range of our observation and we notice them. But the gravitons, finer even than cosmic rays, are just beyond our present range of perception, and so we do not observe them at all, but only detect their effect. This is just as Modern Physics assumes the existence of *neutrinos*, suggested by Pauli, although they have not yet been actually observed. There is absolutely no reason why the emanations from matter must be confined to only those radiations which our present day instruments can measure, as if Nature's limits are fixed by our capacity to observe them.

## SECTION II

### SELF-ACCELERATION

1 Newton's first law of motion was that a body will continue to move in a straight line with the same velocity for all time to come so long as it is not disturbed by an extraneous force. The same uniformity of motion is assumed in Relativity. But the theory of emission of gravitons necessarily leads to the conclusion that this is not so, when a body is both moving and simultaneously emitting gravitons. As a result of its motion, there would be less emission at the front than at the rear, the difference in the losses of momenta causing an automatic acceleration in the direction of motion.

2 Ordinarily radions and gravitons would leave their systems, when after innumerable revolutions they attain the parabolic velocity. (See Chapter II, Section VII, para 2) As explained in the Unified Theory the gravitons leave a body when they attain the limiting parabolic velocity  $D$ . But the stellar conditions owing to the prevalence of high temperatures are quite different from terrestrial conditions. If a physical explanation were wanted, it can be supposed that gravitons emerge as a result of a sudden explosion of a sub-atomic shell so that its fragments fly off with equal momentum in space along the radii. As the gravitons are the cause of gravitation and are not themselves subject to gravitation,

their velocity is unaffected by the gravitational attraction of the star or nebula

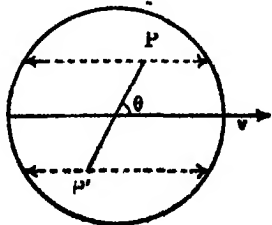
3 For purposes of this chapter it is not necessary to make any assumption as regards gravitons other than what Einstein has assumed for light and what de Sitter has inferred from his test of binary stars, *viz.*, that the velocity of gravitons in space is independent of that of its source. Thus, if a body be moving with velocity  $v$ , then two tiny fragments (*i.e.*, gravitons) of masses  $\mu$  at the front and at the rear will emerge with momenta

$$\begin{aligned} \mu v + (\mu D - \mu v) &= +\mu D \\ \text{and} \quad \mu v - (\mu D + \mu v) &= -\mu D \end{aligned}$$

These are independent of the original velocity  $v$

4 Thus gravitons leave a body with the limiting velocity  $D$ . And so each possesses a momentum  $\mu D$ . If the body from which it emerges is stationary, each of the gravitons on either side takes away a momentum  $+\mu D$  and  $-\mu D$  respectively from it, in which case the emission causes no acceleration as the net result is zero. But if the body were moving with velocity  $v$  in one direction, there would have been no effect on the remaining mass if the gravitons emerging in the same direction were to go off with momentum  $\mu v$  each. But each actually goes off with  $\mu D$ . And so the momentum that affects the remaining mass is  $\mu(D - v)$  instead of  $\mu D$ . There is thus a saving of momentum  $\mu v$ . On the other hand, in the rear the graviton in order to acquire a velocity  $D$  in space has to take away a momentum  $-\mu(D + v)$  because it had a velocity  $+v$  along with the body. Hence the effect of the difference in the losses of momenta at corresponding points in the front and the rear is a net saving of  $2\mu v$ , which is effective as a gain in the direction of the motion of the body

5 If we take two corresponding points  $P$  and  $P'$  inside a sphere which is moving with velocity  $v$ , and gravitons start from  $P$  and  $P'$  with velocities  $\pm D$  parallel to  $v$ , then those travelling in the direction of  $v$  will take a longer time to reach the surface and to leave the sphere than those travelling in the opposite direction. It is easy to see that the frequency of emission, *i.e.*, the losses of gravitons in the front would be diminished in the ratio  $\left(1 - \frac{v}{D}\right)$  whereas that



at the rear will be increased in the ratio  $\left(1 + \frac{v}{D}\right)$ . If each graviton

carries away a momentum  $\pm \mu D$ , then the difference in the momenta of corresponding gravitons is  $-2\mu D$ . Hence the net gain to the remaining mass is  $+2\mu D$  in the direction of motion. (191) It follows that an isolated body moving in space accelerates its motion.

6. Were it to be wrongly assumed, as in Relativity, that the velocity of the emerging graviton *with respect to the body* is constant and is the same on both sides, then the losses in the front and at the rear would be  $\mu(D+v)$  and  $\mu(D-v)$ , the net result being a retardation of motion instead of acceleration.

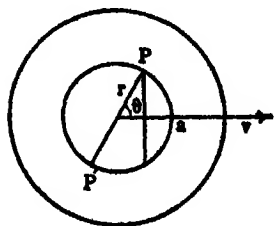
There is an equal fallacy in the supposition<sup>17</sup> that when a star is moving forwards the emitted radiation is rather heaped up in front and thinned out behind, and as radiation exerts pressure, the pressure will be stronger on the front than on the rear causing retardation. This would imply that old stars should have lower speeds than young stars, which is contrary to observation. As the speed of radiation is very much greater no part of the emitted radiation can really lag behind to exert any backward pressure at all.

### SECTION III

#### THE COSMICAL CONSTANT

1. If all particles of a sphere emit gravitons in all directions, it is easy to see that the effect will be the same as if the entire mass were concentrated at the centre, and the gravitons were emitted from the centre. If a sphere were divided into a series of thin concentric spherical shells, the result is the same as if the mass of each shell were emitting gravitons from every point in the shell along its radial distance.

2. Let a spherical mass of radius  $a$  be moving with velocity  $v$ . Let  $n$  be the number of gravitons emanating from unit mass per unit time,  $\mu$  and  $D$  the mass and velocity of each.



Consider a spherical shell of radius  $r$  and  $r+dr$ , and take its section which is at right angles to the motion of the sphere and subtends an angle  $2\theta$  at the centre. Let  $\rho$  be the density. Then the mass of a disc  $= (2\pi r \sin \theta r d\theta dr \rho)$ . The resolved velocity of the point  $P$  along the radius is  $v \cos \theta$ . The gravitons emerging radial-

ly from  $P$  and  $P'$  would therefore yield a net momentum  $2\mu v \cos \theta$ , which resolved along the path of motion of the sphere gives  $2\mu v \cos^2 \theta$ . Hence

the total gain in momentum in the direction of  $v$  per unit time

$$\begin{aligned}
 &= \int_0^a \int_0^{\pi/2} 2\pi r \sin\theta \, r \rho \, 2\mu v \cos^3\theta \, n \, d\theta \, dr \\
 &= n\mu \frac{4\pi}{3} v \rho \frac{a^3}{3} \\
 &= \frac{Mv}{3} (n\mu), \text{ where } M \text{ is the total mass of the sphere}
 \end{aligned}$$

Hence the acceleration caused to the sphere by its own motion is

$$\frac{d^2R}{dt^2} = \left(\frac{n\mu}{3}\right) v = \gamma \frac{dR}{dt} \quad (201)$$

where  $\gamma$  is the Cosmical Constant

$$\text{The dimensions of } \gamma \text{ are } = n\mu = \frac{1}{MT} \quad M = \frac{1}{T}$$

3 *Alternative method* Let  $n$  be the number of gravitons emanating per unit mass per unit time,  $\mu$  the mass of each, and  $D$  its velocity

Then the number of gravitons emerging through a solid angle  $du$  cause a loss of momentum  $= nM \frac{du}{4\pi} dt \, \mu D$ , if the body be at rest

But if the body is moving with velocity  $v$ , then at  $P$ , making an angle  $\theta$ , the loss  $= nM \frac{du}{4\pi} dt \, \mu (D - v \cos\theta)$ . Similarly the loss at  $P'$   $= -nM \frac{du}{4\pi} dt \, \mu (D + v \cos\theta)$  Resolving these two along the direction of motion, the combined gain  $= 2 nM \frac{du}{4\pi} dt \, \mu v \cos^2\theta$

$$\text{Now } \int_0^{\pi/2} \cos^2\theta \, du = \int_0^{\pi/2} \cos^2\theta \, 2\pi \sin\theta \, d\theta = \frac{2\pi}{3}$$

Therefore the real change in loss of momentum

$$= \frac{M}{3} (n\mu) v dt$$

$$\text{Hence the acceleration} = \frac{n\mu}{3} v$$

$$\frac{d^2R}{dt^2} = \frac{n\mu}{3} \frac{dR}{dt} = \gamma \frac{dR}{dt}$$

where  $\gamma = \frac{n\mu}{3}$  is the Cosmical Constant ... .. (201)

$$4 \quad (i) \text{ If } \frac{d^2 R}{dt^2} = \gamma \frac{dR}{dt}, \text{ then } \frac{dR}{dt} = \gamma R + A_0 \quad (20'2)$$

Multiplying by  $e^{-\gamma t}$  we get  $\frac{d}{dt} (R e^{-\gamma t}) = A_0 e^{-\gamma t}$

$$R = -\frac{A_0}{\gamma} + B_0 e^{\gamma t}.$$

$$\text{This can be written as } R = A e^{\gamma t} + B \quad \dots (203)$$

$$(ii) \text{ Now if } R = A e^{\gamma t} + B$$

$$\text{then } \frac{dR}{dt} = \gamma A e^{\gamma t} = \gamma (R - B)$$

$$\frac{d^2 R}{dt^2} = \gamma^2 A e^{\gamma t} = \gamma^2 (R - B) = \gamma \frac{dR}{dt}$$

If  $R = R_0$  and  $v = v_0$  when  $t=0$ , then

$$\frac{dR}{dt} = \gamma R + (v_0 - \gamma R_0) \quad (204)$$

$$\text{and } R = \frac{v_0}{\gamma} e^{\gamma t} + \left( R_0 - \frac{v_0}{\gamma} \right) \quad (205)$$

#### SECTION IV

##### PROPORTIONALITY TO DISTANCE LAW

$$1 \quad \text{In relativity for a particle at rest, } \frac{d^2 r}{ds^2} = \frac{1}{2} \lambda r (1 - \frac{1}{2} \lambda r^2) \left( \frac{dt}{ds} \right)^2$$

$$\text{and } \left( \frac{dt}{ds} \right)^2 = \frac{1}{(1 - \frac{1}{2} \lambda r^2)} \quad \dots (211)$$

$$\text{Hence } \frac{d^2 r}{ds^2} = \frac{1}{2} \lambda r$$

As light cannot cross the barrier, one is limited to the region where  $(1 - \frac{1}{2} \lambda r^2)$  is positive. Hence there are no reasonable conditions which encourage a motion towards the origin. The force of repulsion acts away from the origin; and the velocity also is one of recession

$$2 \frac{dr}{ds} \frac{d^2 r}{ds^2} = \frac{1}{2} \lambda r^2 \frac{dr}{ds}.$$

$$\therefore \left( \frac{dr}{ds} \right)^2 = \frac{1}{2} \lambda r^2 + A \text{ and so } \frac{dr}{ds} = + \sqrt{\frac{1}{2} \lambda r^2 + A} \quad (21'2)$$



The velocity is proportional to distance only if the constant is taken to be zero. Relativity is utterly unable to explain how some nebulae, including the great Nebula in Andromeda, can be approaching.

As both the acceleration and the velocity are positive when measured away from the origin and most nebulae are moving away from the earth with velocities proportional to their distances, it would seem that the earth is the centre of the explosion—an unreasonable conclusion.

The stars on the opposite sides of a diameter of the Galactic system are 250,000 light years apart and as one light year =  $9.4 \times 10^{17}$  cm, their distances are about  $2.4 \times 10^{24}$  cm. And yet their velocities do not scatter them away.

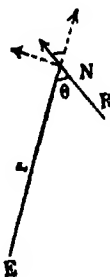
2 (i) In the *New Theory*  $\frac{d^2 R}{dt^2} = \gamma \frac{dR}{dt}$ , where  $R$  may be measured in any direction and from any origin. The acceleration is proportional to the velocity and is in the direction of the velocity. Their components along the line of sight will have the same proportion. And the nebula can be either receding or approaching. The component along the line of sight is  $\frac{dr}{dt} = \frac{dR}{dt} \cos \theta$ , which is observable by means of the spectral shift.

The component normal to it is  $\frac{rd\theta}{dt} = \frac{dR}{dt} \sin \theta$  and is not observable.

(ii) It has been shown that the self-acceleration is proportional to velocity and is along the direction of the motion. So if a nebula were moving in a direction making an angle  $\theta$  with the line of sight from the earth and  $R$  be measured along that direction and  $r$  along the line of sight then

$$\frac{d^2 R}{dt^2} = \gamma \frac{dR}{dt} \quad \frac{d^2 r}{dt^2} \cos \theta = \gamma \frac{dr}{dt} \cos \theta$$

Hence  $\frac{d^2 r}{dt^2} = \gamma \frac{dr}{dt} \dots \dots (21.3)$



Here  $\gamma$  is a universal constant. On integration the equation gives the approximate proportionality to distance law for the component velocity along the line of sight.

(iii) We thus get a Cosmological Principle that the relation of the acceleration and velocity of a moving body presents the same picture to an observer, no matter where he is placed. The earth need not be at the centre of the Universe and we may be looking at a nebula from any position in space, the ratio of the acceleration to velocity still remains the same, and they can be both positive or both negative. In Relativity a

nebula must be moving in a direction away from the earth as origin, whereas in the New Theory it can be moving in any direction, it is only the resolved component of its velocity along the line of sight which causes the spectral shift

(iv) It was shown in Chapter III Section VI that loss of frequency of light can be due to several causes and would be proportional to distance. If the loss in frequency due to causes other than recession be  $-\Delta\nu = g r$ ,

$$\text{then } \Delta\lambda = \frac{g \lambda^2}{c} r, \text{ nearly}$$

Now, if the nebula is receding with velocity  $v$  then,  $(v + \delta v) = (1 - \frac{v}{c}) v$

$$\lambda + \delta\lambda = (1 + \frac{v}{c}) \lambda \quad \text{Hence } \delta\lambda = \frac{v}{c} \lambda \quad (21.4)$$

Hence if  $d\lambda$  be the observed shift, then the real shift due to recession

$$\text{is } \delta\lambda = d\lambda - \Delta\lambda = d\lambda - \frac{g \lambda^2}{c} r \quad (21.5)$$

$$\text{Accordingly } v = \frac{\delta\lambda}{\lambda} c = (d\lambda - \frac{g \lambda^2}{c} r) \frac{c}{\lambda} = (\gamma - g \lambda) r$$

$$\text{where by observation } \frac{\Delta\lambda}{\lambda} \cdot c = \gamma r \quad \dots \quad (21.6)$$

Thus the real recessional velocities of the nebulae may be considerably smaller than the observed recessional velocities

## SECTION V

### SURFACE RADIATION

1 Even if the emission of gravitons from the entire mass be not assumed, and it be only supposed that light particles are emitted from an outer shell of radii  $a_1$  and  $a_2$  then from Section III §2 the total gain of momentum from the light radiation alone will be

$$\begin{aligned} &= \int_{a_2}^{a_1} \int_0^\pi 2\pi r \sin \theta \cdot r \cdot \rho \cdot 2\mu v \cos^2 \theta \cdot n \cdot d\theta \cdot dr \\ &= 4\pi \mu \cdot n \cdot v \int_{a_2}^{a_1} \int_0^\pi \cos^2 \theta \sin \theta \cdot r^2 \cdot \rho \cdot dr \cdot d\theta. \end{aligned} \quad (21.7)$$

(i) Assume that density is uniform, then  $\rho$  is constant

$$\begin{aligned}\text{the gain} &= 4\pi \frac{\mu n}{3} v \rho \frac{a_1^3 - a_2^3}{3} \\ &= (4\pi a_1^3 \rho) \frac{\mu n v}{3} \left(1 - \frac{a_2^3}{a_1^3}\right) \\ &= M \frac{\mu n}{3} v \left(1 - \frac{a_2^3}{a_1^3}\right)\end{aligned}$$

Hence 
$$\frac{d^2 R}{dt^2} = \gamma' v = \gamma' \frac{dR}{dt}$$

(ii) If  $\rho = \frac{m}{r}$ , where  $m$  is constant, then

$$\text{the gain} = (2\pi m a_1^2) \cdot \frac{\mu n}{3} v \left(1 - \frac{a_2^3}{a_1^3}\right)$$

$$\text{But the mass} = \int_0^{a_1} \frac{m}{r} \pi 4\pi r^2 dr = 2\pi m a_1^2,$$

Hence again 
$$\frac{d^2 R}{dt^2} = \gamma' v = \gamma' \frac{dR}{dt}.$$

(iii) If 
$$\rho = \frac{m}{r^2},$$

then the gain 
$$= M \frac{\mu n}{3} v \left(1 - \frac{a_2^3}{a_1^3}\right)$$

and so on.

Hence the same relation between the acceleration and the velocity holds in the case of the surface radiation also, only the constants are different

2 If a nebula has mass  $M$ , radius  $a$  and radiation  $\sigma$  per unit surface area per second, then  $\frac{4\pi a^2 \sigma \times 3 \times 10^{10}}{M} = \gamma \cdot v$ , if light radiations alone were effective. The substitution of the observed values will test whether this is possible. The time when the nebulae left our galactic system would be increased considerably, if radiations from an outer shell only are the cause of its acceleration.

## SECTION VI

### THE RECEDING AND APPROACHING NEBULÆ

1. The galactic system is estimated to have the weight of about  $18 \times 10^{10}$  suns, and the distance of the Great Nebula (M 31 in Andromeda) is  $9 \times 10^6$  light years.

If the nebula were just on a parabola round the G S

$$v_1^2 = \frac{2GM}{R} = \frac{2 \times 18 \times 10^{10} \times 1.98 \times 10^{33} \times 6.673 \times 10^{-8}}{9 \times 10^6 \times 9.463 \times 10^{17}} = 5.52 \times 10^{11}$$

But the observed velocity after making deduction for the galactic rotation is  $v_r^2 = (20 \times 10^5)^2 = 4 \times 10^{12}$ , which would be within the limiting velocity. Hence the nebula is still a part of the galactic system and is revolving round it in a nearly elliptic orbit.

2 It is submitted that the weight of the galactic system has been much under-estimated, because it is difficult to estimate the total number of the invisible stars and the total weight of clouds of matter at the outer fringe of the Milky Way. It is also probable that the distances of nebulae are over-estimated. Lastly, the real shift is less than the apparent shift. Thus the limiting velocity for the effective range of the galactic system may be much larger, and so a very large majority of the nebulae may still be parts of our system.

3. All the nebulae, which have greater velocities, are going away on hyperbolas, hence the resolved components of their velocities always show recession. This is why no nebula with a velocity greater than the limiting velocity is found to be approaching. These may pass on to some other galactic system like electrons passing on from one atom to another.

On the other hand, all the nebulae having velocities less than the limiting value are still moving in ellipses round the G S, and so some are seen to be approaching and some receding according to their position in the orbits.

4 Another possible, but improbable, hypothesis can be that the approaching nebulae left some other galactic system, and so happen to be coming towards our galactic system, just as nebulae leaving our galactic system may by chance happen to pass close by another galactic system and be caught by it.

#### SECTION VII

1 When the acceleration proportional to velocity along the path of motion is taken into account an additional term  $\frac{d^3s}{dt^3} = \gamma \frac{ds}{dt}$  has to be included in the equations of motion, which in place of (5.41) and (5.7) take the following forms.—

$$\frac{1}{r} \frac{d}{dt} \left( r^3 \frac{d\theta}{dt} \right) = \frac{\mu}{r^3} \frac{r}{D} \frac{d\theta}{dt} + \gamma r \frac{d\theta}{dt} \quad \dots \quad (22.1)$$

$$\text{and } \frac{d^3r}{dt^3} - r \left( \frac{d\theta}{dt} \right)^3 = - \frac{\mu}{r^3} - \frac{3\mu}{D^2} \frac{1}{r^3} \left( r^3 \frac{d\theta}{dt} \right)^2 + \frac{3\mu}{D} \frac{1}{r^3} \frac{dr}{dt} + \gamma \frac{dr}{dt} \quad (22.2)$$

It is noteworthy that the additional terms are not only independent of the mass of the influenced body, but also of that of the influencing body. Hence in the solar system, where the sun has a huge mass, the effect of the additional terms is almost negligible. It is only after a comet has started on a parabolic path, that the influence of the sun diminishes and the effect of self-acceleration increases. The same is of course true of a nebula leaving the galactic system by reaching the parabolic velocity.

2 It is easy to see that if the galactic system and a nebula forming part of it, were both moving through space with the same velocity, the self-acceleration of both due to their velocity will always remain equal. The same would be the case even after the nebula has separated from the galactic system. But its recessional velocity, as seen from the galactic system, would be caused exclusively by the additional acceleration due to its relative motion. But if the nebula is emitting matter,  $\sigma g$ , light at a higher rate than the galactic system it will have a greater acceleration. In that event the nebulae that have left our system will be more crowded in the direction of the motion. It is actually found that the density of the nebulae distribution to the north of the Milky Way is greater than in the south (Shapley) <sup>18</sup>. So the galactic system is moving towards the North side.

## SECTION VIII

### THE STABLE UNIVERSE

1 The extra-galactic island nebulae are like miniature galactic systems, in all respects similar to ours, possessing numerous stars, comets and dust clouds. These miniature galactic systems are or were revolving round our galactic system as nucleus, or more accurately round the common centre of gravity, just as planets revolve round the sun.

2 Their orbital velocity was gradually increased owing to the net attractive pull as well as their self-acceleration, till the more distant ones attained the limiting velocity equal to  $\frac{2M}{R_0}$ , when they started on a parabolic path not likely to return to the galactic system.  $R_0$  is of course different for each nebula.

3. These are travelling on the arms of straightened parabolas, at different inclinations to the line of sight. But only their radial velocity is observable because of the shift of the spectral lines, as light alone is a measuring instrument for such huge distances. Their transverse velocity cannot be measured, as the distance is too large and the change of angle

too small. As the observed velocities of most of these nebulae are much greater than the limiting velocity, they left the galactic system long ago

4 But the nearer nebulae have less than the limiting velocity, and so they are still revolving round our galactic system in huge orbits. Some are approaching and some receding according to their positions in their nearly elliptic orbits.

5 The universe is perfectly stable, and is not exploding. Only some nebulae, which were at one time parts of our galactic system, have left it on parabolic paths. They will travel away until they are caught by some other huge galactic system like our own, which owing to its distance is not yet visible to us. Their passage would be like electrons from atom to atom.

6 All such galactic systems would form parts of a bigger super-galactic system. Such super-galactic systems would in their turn form parts of a Meta-galactic system; and so on, beyond the comprehension of the human mind. They all have the same features as the solar system, though on a much more gigantic scale. Space is not at all so finite and surprisingly small as Einstein conceives it to be. But howsoever far we see, space is strictly three-dimensional, and there is absolutely no evidence that the spatial phenomena are anything but three dimensional. A four-dimensional continuum, obtained by confusing time with space, is not at all called for to explain the Universe.

## CHAPTER V

### Special Relativity

#### SECTION I

#### COMMON TIME AND DISTANCE

1 Newton, starting with common absolute space and time for all moving bodies, assumed that dynamically the relative velocity between two bodies is exactly the same as if either were reduced to rest, and the other were moving with the difference in their velocities. If two bodies were moving with absolute velocities  $u$  and  $v'$ , and  $v$  be their relative velocity, then  $v = v' - u$ . Newton would have been right if  $v'$  and  $u$  could be measured instantaneously by means of a messenger travelling with infinite velocity or by an omniscient superman.

2 In Einstein's Relativity it is considered impossible to have a common time between two bodies. Each body is supposed to keep its own separate time, and there is no method by which both can measure exactly the same time, except by the impossible assumption that light from the first to the second takes the same time as light from the second to the first "We have hitherto an A-time, and a B-time, but no time common to A and B. This last time (i.e., common time) can be defined, if we establish by definition that the time which light requires in travelling from A to B is equivalent to the time which light requires in travelling from B to A " (Einstein) <sup>19</sup> But in reality the times taken by light are not equal, as  $\frac{r}{c-v} \neq \frac{r}{c+u}$  for all values of  $u$  and  $v$

3. But there is a method according to which two moving bodies can measure *exactly* the same time and can calculate *exactly* the same distance between them. This is the method of Reflection or Double journey A messenger is sent out from A to B and returns as soon as it meets B and then meets A and the time taken by the messenger is measured by A. Another messenger is sent by B to A and after meeting A returns to B and meets B, and the time taken by the messenger is measured by B. If the two messengers travel with the same absolute velocity D, it can be shown dynamically that the times measured by A and B separately are exactly the same It can also be shown dynamically that the distances between A and B as calculated by both separately are exactly the same.

4. But both A and B labour under a mistake. Each regards himself as if he were at rest and the other moving away from him with the difference in their absolute velocities between them Or he wrongly assumes with Newton that no matter what his own absolute velocity may be, he gets the correct result by reducing himself to rest and taking the difference between the two velocities as the relative velocity But in point of fact, the relative velocity between them depends not only on the difference in their absolute velocities, but also to some extent on the absolute velocities themselves. The assumption that only the difference in the absolute velocities comes into play causes an error in the Newtonian law, for which a correction is necessary when account is taken of their absolute velocities.

5. Newton's absolute space and time were philosophically conceivable and mathematically workable, though not actually measurable. The relative velocity between two bodies moving uniformly was in absolute space and time, an exact, determinate quantity, if their velocities could be

measured instantaneously Einstein has rejected absolute space and time, simply because they are not actually measurable, and regards relative velocity as a measurable quantity. But if the absoluteness of space and time be rejected, then relative velocity also becomes an uncertain quantity. If relative velocity only means relative velocity as actually observed and we go exclusively by measurements only, then the relative velocity between two bodies would depend on the particular method of measurement chosen. It will be shown in the next paper that the value would vary as the method is changed. Further, a personal equation will come in according as one body or the other is taken as source or observer. But the relative velocity between the two moving bodies ought to be the same, quite independent of any such personal equation.

## SECTION II

### THE REAL AND APPARENT VELOCITIES

1. Let A and B be moving with velocities  $u$  and  $v'$  respectively. Let a messenger be sent out from A to B, overtake it at  $A''$  and return to A and meet it at  $A''$  and let the messenger travel with the velocity  $D$ , and let  $AB = r$ . Let  $A'$  be the position of A when B is at  $B'$ .

Then the real time taken from A to  $B'$  + the real time taken from

$$B' \text{ to } A'' = \frac{AB}{D-v'} + \frac{A'B'}{D+u} = \frac{r}{D-v'} + \frac{r + \frac{r}{D-v'} v' - \frac{r}{D-v'} u}{D+u}$$

$$= \frac{2 D r}{(D-v')(D+u)} \quad \dots (23.1)$$

Thus the real time taken for the double journey is  $t_1 + t_2$

$$= \frac{2 D r}{(D-v')(D+u)}$$

The real distance between  $A''$  and  $B''$  after the messenger has returned is  $A''B'' = A''B' + B'B''$

$$= \frac{r + \frac{r}{D-v'} v' - \frac{r}{D-v'} u}{D+u} \cdot D + \frac{r + \frac{r}{D-v'} v' - \frac{r}{D-v'} u}{D+u} \cdot v'$$

$$= \frac{r (D-u) (D+v')}{(D+u) (D-v')} \quad \dots \dots (23.2)$$



Now suppose that a messenger is sent out from B, reaches A at  $A_1$  and returns to B at  $B_1$ , and that B is at  $B_1$  when A is at  $A_1$

Then the real time taken by the messenger from B to  $A_1$  + the real time taken from  $A_1$  to  $B_1$

$$= \frac{AB}{D+u} + \frac{A_1 B_1}{D-u} = \frac{r}{D+u} + \frac{r + \frac{r}{D+u} \cdot v' - \frac{r}{D+u} u}{D-v'} \quad \dots \quad (23.3)$$

Thus the real time  $t_1 + t_2$  is the same as (23.1)

The real distance between  $B_1$  and  $A_1$  after the messenger has returned to B is  $B_1 A_1 = B_1 A_1 - A_1 A_2$

$$= \frac{r + \frac{r}{D+u} v' - \frac{r}{D+u} u}{D-v'} - D = \frac{r + \frac{r}{D+u} v' - \frac{r}{D+u} u}{D-v'} u$$

$$= \frac{r(D-u)(D+v')}{(D+u)(D-v')} \quad \dots \quad (23.4)$$

Thus the real distance between  $B_1$  and  $A_1$  is the same as that between  $A''$  and  $B''$  in (23.2)

It follows that both A and B measure the same time and the same distance if they both employ messengers travelling with the same velocity

2. But A regards himself at rest, and assumes that B is moving away from him with velocity  $(v'-u)$ .


Then the apparent time as measured by A when a messenger sent out from A returns from B to A, is  $2t$

$$= \frac{r}{D-(v'-u)} + \frac{r}{D-(v'-u)} = \frac{2r}{D-v'+u} \quad (23.5)$$

for, according to him the messenger will take the same time to overtake B as to return to A after overtaking B, as A is supposed to be at rest

The apparent distance between A and  $B''$  according to him is

$$A B'' = r + \frac{2r}{D-v'+u} \cdot (v'-u) = \frac{D+v'-u}{D-v'+u} \cdot r \quad \dots \quad (23.6)$$

On the other hand, B regards himself as at rest, and  assumes that A is moving away from him with velocity  $(v' - u)$  in the opposite direction.

Hence the apparent time measured by B is the same and

$$= \frac{2r}{D - v' + u}.$$

Similarly the apparent distance between B and A'' is the same and

$$= \frac{D + v' - u}{D - v' + u} r$$

Thus both A and B measure exactly the same apparent time and distance.

3 Therefore owing to the simultaneous motions of both the bodies instead of a distance  $r$  we have a real distance (23 2)

$$\frac{(D - u)(D + v')}{(D + u)(D - v')} r$$

and instead of time  $\frac{2r}{D}$  we have a real time (23 1)

$$\frac{2Dr}{(D - v')(D + u)}$$

while instead of  $r$  we have an apparent distance (23 6)

$$\frac{D + v' - u}{D - v' + u} \cdot r$$

and instead of time  $\frac{2r}{D}$  we have an apparent time (23 5)

$$\frac{2r}{D - v' + u}$$

Similarly  $(r + dr)$  becomes  $\frac{(D - u)(D + v')}{(D + u)(D - v')} (r + dr)$

$$\text{and } \frac{D + v' - u}{D - v' + u} \cdot (r + dr) \text{ respectively,}$$

and  $\frac{2(r + dr)}{D}$  becomes  $\frac{2D(r + dr)}{(D - v')(D + u)}$ ,

$$\text{and } \frac{2(r + dr)}{D - v' + u} \text{ respectively.}$$

Hence an infinitesimal distance  $dr$  becomes a real distance

$$= \frac{(D-u)(D+v')}{(D+u)(D-v')} \cdot dr$$

and an apparent distance  $= \frac{D+v'-u}{D-v'+u} dr$

while an infinitesimal time  $\frac{2dr}{D}$  becomes a real time

$$= \frac{2Ddr}{(D-v')(D+u)}$$

and an apparent time  $= \frac{2dr}{D-v'+u}$

It follows that the *real* relative velocity  $(v'-u)$  changes in the ratio

$$= \left\{ \frac{(D-u)(D+v')}{(D+u)(D-v')} - \frac{D^2}{(D-v')(D+u)} \right\} = \frac{(D+v')(D-u)}{D^2} \quad (23.7)$$

and the *apparent* relative velocity  $v$  changes in the ratio

$$= \left\{ \frac{D+v'-u}{D-v'+u} - \frac{D}{D-v'+u} \right\} = \frac{(D+v'-u)}{D} \dots \dots (23.8)$$

Thus instead of Newton's formula  $v=v'-u$  we have

$$\begin{aligned} \frac{v}{v'-u} &= \frac{D(D+v'-u)}{(D+v')(D-u)} \\ &= \frac{1 + \frac{v'}{D} - \frac{u}{D}}{\left(1 + \frac{v'}{D}\right)\left(1 - \frac{u}{D}\right)} \dots \dots (23.9) \end{aligned}$$

$$\begin{aligned} &= \frac{1 + \frac{v'}{D} - \frac{u}{D}}{1 + \frac{v'}{D} - \frac{u}{D} - \frac{v'u}{D^2}} \\ &= \frac{1}{1 - \frac{v'u}{D^2} + \frac{v'^2 u}{D^3} - \frac{v'u^2}{D^3} + \dots} \quad (23.10) \end{aligned}$$

$$= \frac{1}{1 - \frac{v'u}{D^2}} \text{ nearly } \dots \dots (23.11)$$

This corresponds in form with the famous formula assumed by Einstein for the addition of relative velocities in special Relativity with light as the messenger, which is not rigorously true but only approximately so. The correspondence with Einstein's formula comes in because the relative velocities of a moving point with reference to two moving systems correspond with the absolute velocities of those systems when the third is a point at rest in space

4 If we put  $v'$  for  $v$ ,  $v$  for  $v'$  and  $-u$  for  $u$

$$\text{then } \frac{v'}{v+u} = \frac{1 + \frac{v}{D} + \frac{u}{D}}{\left(1 + \frac{v}{D}\right) \left(1 + \frac{u}{D}\right)} = \frac{1 + \frac{v}{D} + \frac{u}{D}}{1 + \frac{v}{D} + \frac{u}{D} + \frac{vu}{D^2}} \quad (23.12)$$

$$= \frac{1}{1 + \frac{vu}{D^2} - \frac{v^2 u}{D^2} - \frac{vu^2}{D^2} + \dots} \quad (23.13)$$

$$= \frac{1}{1 + \frac{vu}{D^2}} \text{ nearly} \quad \dots \quad (23.14)$$

The significance of this converse formula, which may not be apparent, will be shown later.

5 If  $u$  and  $v'$  be not the absolute velocities in space, but velocities relative to a point moving with an unknown absolute velocity  $x$ , then the formulae can be easily seen to be

$$\frac{v'}{v'-u} = \frac{1 + \frac{v'+x}{D} - \frac{u+x}{D}}{\left(1 + \frac{v'+x}{D}\right) \left(1 - \frac{u+x}{D}\right)} \quad (23.15)$$

$$\text{and } \frac{v'}{v+u} = \frac{1 + \frac{v+x}{D} + \frac{u+x}{D}}{\left(1 + \frac{v+x}{D}\right) \left(1 + \frac{u+x}{D}\right)} \quad (23.16)$$

6 If the two points A and B be moving with the same velocities then  $v' = u$ .

Hence from (23.1) the real time is  $t_1 + t_2 = \frac{2D}{(D^2 - u^2)} r$

" (23.2) " distance =  $r$ .

" (23.5) the apparent time is  $2t = \frac{2r}{D}$

" (23.5) " distance is =  $r$

And although  $v'-u = 0$  and therefore  $v = 0$ , the ratio

$$\frac{v}{v'-u} = \frac{1}{1 - \frac{u^2}{D^2}}$$

### The First Universal Principle

The relative velocity  $v$  between two bodies moving with velocities  $u$  and  $v'$ , measured by employing a messenger travelling with velocity  $D$  in a to-and-fro journey, is given by the formula

$$\frac{v}{v'-u} = \frac{1 + \frac{v'}{D} - \frac{u}{D}}{\left(1 + \frac{v'}{D}\right) \left(1 - \frac{u}{D}\right)}$$

**The Corollary.**—When two bodies are moving with the same constant velocity  $u$  in the same direction, the ratio of their apparent and real relative velocities, measured by means of a messenger travelling with velocity  $D$  and performing the double journey, is not unity but  $= \frac{1}{1 - \frac{u^2}{D^2}}$

7 *The transformation formulas*—It is assumed in Relativity that a point  $P$  has coordinates  $(x, y, t)$  with reference to a system  $S$  and coordinates  $(x', y', t')$  with reference to a system  $S'$  and that

$$\left. \begin{array}{l} x=0 \text{ and } x' = u_0 t' \\ \text{and } x'=0 \text{ and } x = -u_0 t \end{array} \right\} \text{simultaneously,}$$

where  $u_0$  is the difference of their velocities. So that these assumptions involve the fallacies (1) that their different coordinates can be read off instantaneously, whereas if a messenger be employed he will take time to go from one to the other and back, and (2) that these coordinates are measured when the two systems are alternately at rest, which is not the true fact.

As approximations the assumptions are true, but not rigorously.

(1) The true transformations for a double journey are with the help of (23'2) given by the following set of equations.—

For the origins,  $x = 0$

$$\text{and } x' = \frac{(D-u)(D+v')}{(D+u)(D-v')}. (v'-u). t' = ku_0 \quad \dots \quad (23\ 17)$$

Also  $x' = 0$

$$\text{and } x = -\frac{(D-u)(D+v')}{(D+u)(D-v')} (v'-u)t = -ku_0 \quad (23'18)$$

$$\text{where } k = \frac{(D-u)(D+v')}{(D+u)(D-v')} \text{ and } u_0 = v' - u,$$

and  $t$  and  $t'$  are supposed to be different and represent the whole times taken in the two systems. In reality  $t=t'$

Hence generally,  $\left. \begin{array}{l} \alpha x = x' - ku_0 t' \\ \beta x' = x + ku_0 t \end{array} \right\}$  where  $\alpha$  and  $\beta$  are some constants

$$\text{And therefore } ku_0 t = \beta x' - x = \beta x' - \frac{x' - ku_0 t'}{\alpha}$$

$$\alpha t = \frac{\alpha\beta - 1}{ku_0} x' + t'$$

$$\text{Also as } ku_0 t' = x' - \alpha x = \frac{x + ku_0 t}{\beta} - \alpha x$$

$$\beta t' = \frac{(1 - \alpha\beta)}{ku_0} x + t.$$

(2) If  $V$  and  $V'$  be the velocities of a point relative to the two systems measured instantaneously,

$$\text{then } V = \frac{x}{t} = \frac{x' - ku_0 t'}{\frac{\alpha\beta - 1}{ku_0} x' + t'} = \frac{V' - ku_0}{1 - (1 - \alpha\beta) \frac{V'}{ku_0}} \quad \dots (23'19)$$

$$\text{and } V' = \frac{x'}{t'} = \frac{x + ku_0 t}{\frac{(1 - \alpha\beta)}{ku_0} x + t} = \frac{V + ku_0}{1 + (1 - \alpha\beta) \frac{V}{ku_0}} \quad \dots (23'20)$$

(3) As an approximation, we can put  $k=1$  and then the assumptions in Relativity are nearly true if  $S$  and  $S'$  can be supposed to be alternately at rest.

The transformations then become

$$\text{and } \left. \begin{array}{l} \alpha x = x' - u_0 t' \\ \beta x' = x + u_0 t \end{array} \right\} \quad \dots (23'21)$$

$$\text{Therefore } V = \frac{x}{t} = \frac{x' - u_0 t'}{\frac{\alpha\beta - 1}{u_0} x' + t'} = \frac{V' - u_0}{1 - (1 - \alpha\beta) \frac{V'}{u_0}} \quad \dots (23'22)$$

$$\text{and } V' = \frac{x'}{t'} = \frac{x + u_0 t}{\frac{1 - \alpha\beta}{u_0} x + t} = \frac{V + u_0}{1 + (1 - \alpha\beta) \frac{V}{u_0}} \quad (23'23)$$

## SECTION III

## THE POSTULATES OF RELATIVITY

1 From (23.11) and (23.14) we have the approximate formulae which are not rigorously true —

$$v = \frac{v' - u}{1 - \frac{v'u}{c^2}} \quad \text{and} \quad v' = \frac{v + u}{1 + \frac{v'u}{c^2}}$$

If we make the wrong assumption, as in Relativity, that they are rigorously true for all values of  $v$  and  $v'$  then

if we put  $v' = c$ , we get  $v = c$

and if we put  $v = c$ , we get  $v' = c$

This gives the false result that the velocity of light is absolute and finite velocities added to it or subtracted from it make no difference to it

2 If we apply the above result to the formulae (23.22) and (23.23) we get the approximate results:—

$$c = \frac{c - u_0}{1 - (1 - \alpha\beta) \frac{c}{u_0}} \quad \text{and} \quad c = \frac{c + u_0}{1 + (1 - \alpha\beta) \frac{c}{u_0}}$$

$$\text{Both of these give } \alpha\beta = 1 - \frac{u_0^2}{c^2} \quad . \quad (23'24)$$

3 Now if besides making the two assumptions in Section II § 6, we further wrongly assume, as in Relativity, that the two systems  $S$  and  $S'$  are perfectly equivalent, then by putting  $x'$  for  $x$ , and  $t'$  for  $t$  and  $-u_0$  for  $+u_0$  in (23.21) we get

$$\alpha x = x' - u_0 t'$$

$$\text{and therefore } \alpha x' = x + u_0 t$$

Hence  $\alpha = \beta = \sqrt{1 - \frac{u_0^2}{c^2}}$ , which is the factor in Lorentz transformations

4 These postulates then lead us on irretrievably to the queer results in Special Relativity that

(1) length contracts,

(2) time extends,

and (3) mass increases, with velocity

(See Max Born's Relativity<sup>20</sup> pp. 208, 209 and 228)

5 With the help of these strange transformations, various experimental results like Fresnel's convection formula, Michelson and Morley's

experiment, Bucherer's experiment, Sommerfeld's fine structures of spectral lines are sought to be explained

6 But there is in reality no need to assume these unconvincing postulates or depend on the extraordinary results following from them, for as shown hereafter all the experiments can be easily explained on a simple dynamical principle which is of universal application

#### SECTION IV

##### THE PHYSICAL METHOD

It was pointed out in Chapter I, section IV, that if instead of Newton's assumption that force acts instantaneously, i.e., that it travels with infinite velocity, a finite velocity  $D$  is attributed to the propagation of gravitational force, a correction is necessary for Newtonian Dynamics. That correction was shown to be the same as the result of the compounding of two finite velocities, viz., that if a body were moving with velocity  $v$  in a direction making an angle  $\theta$  with the apparent direction of the force, then if the force be represented by a velocity of propagation  $D$ , it would no longer act effectively in the same direction in which it would have acted if the body had been stationary, but its actual action would be the same as if the body were stationary and the direction of the force were shifted forward by an angle  $\alpha$  given by the ratio applicable to the compounding of the two velocities  $\frac{\sin \alpha}{\sin \theta} = \frac{v}{D}$  (see figures on pp. 7 and 8)

If the effect of the motion of the body is merely to shift forward the direction of the field of force without affecting its intensity, then the component force which we observe along its direction would be  $D \cos \alpha$ . It follows that the correction to be introduced in Newtonian Mechanics in order to make it applicable to forces propagated with a finite velocity  $D$ , when applied to bodies moving with velocity  $v$  making an angle  $\theta$  with the apparent direction of the force, is simply to reduce the intensity of that force by that factor. This simple correction to Newtonian Mechanics gives us all the results of Einstein's Relativity without his extraordinary assumptions. If  $\phi$  be the angle between the real direction of the force and the direction of the body, then the angle of the shift is given by the equation

$$\frac{\sin \alpha}{\sin(\phi - \alpha)} = \frac{v}{D}. \quad \text{Hence if the force be perpendicular } \alpha = \tan^{-1} \frac{v}{D}.$$



For all heavenly bodies  $\frac{v}{D}$  is small, and so for all practical purposes  $\tan \alpha \approx \sin \alpha = \frac{v}{D}$  and therefore  $\cos \alpha = \frac{1}{\sqrt{1 + \frac{v^2}{D^2}}} = \sqrt{1 - \frac{v^2}{D^2}}$  nearly

This principle of aberration which is merely the necessary result of the compounding of two dynamical velocities is of general application, and may be stated as

### The Second Universal Principle

Wherever there is a uniform field of force which takes time to act, and can therefore be represented by a velocity of flow  $D$ , no matter whether of gravitation or radiation or electric or magnetic field, then its action on a body moving uniformly with velocity  $v$  inclined at an angle  $\phi$  to the real direction of the flow, is exactly the same as if the body were stationary and the direction of the flow were shifted forward by an angle  $\alpha$  given by the ratio applicable to the compounding of the two velocities  $\frac{\sin \alpha}{\sin (\phi - \alpha)} = \frac{v}{D}$ ,

so that when the angle is a right angle,  $\alpha \approx \tan^{-1} \frac{v}{D} = \sin^{-1} \frac{v}{D}$  nearly

In most experiments with light it is only the apparent direction of the light that is seen, and so when the motion is perpendicular to the apparent direction of light,  $\theta = \frac{\pi}{2}$  and the factor is  $\sqrt{1 + \frac{v^2}{D^2}}$  exactly

Thus if  $D$  represent the velocity of the flow, it follows by the simple process of the compounding of velocities that the effect of the motion of the body is merely to decrease the magnitude of the force along its apparent direction by the factor

$$\cos \left( \sin^{-1} \frac{v}{D} \right) = \sqrt{1 - \frac{v^2}{D^2}}$$

This process gives a physical explanation of the illusory character of the absoluteness and the maximum speed of light

### SECTION V

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### MINKOWSKI'S EQUATION

1. If as a first approximation we start with the assumption that the intensity of the force is reduced by the factor  $\cos \alpha = \sqrt{1 - \frac{v^2}{D^2}}$  along its direction, then we can by parity of reasoning deduce that the effective

velocity  $c_1$  of light on a body moving with velocity  $v$  at right angles to the direction of the light will be given by the ratio

$$c_1 = c \cos \alpha = c \sqrt{1 - \frac{v^2}{c^2}}$$

$$\begin{aligned} c_1^2 dt^2 &= c^2 dt^2 \left(1 - \frac{v^2}{c^2}\right) = c^2 dt^2 \left(1 - \frac{1}{c^2} \frac{(dr)^2}{(dt)^2}\right) \\ &= c^2 dt^2 - dr^2 = c^2 dt^2 - (dx^2 + dy^2 + dz^2) \\ &= ds^2 \end{aligned}$$

if the projection of the effective path of light along the real direction be taken to be  $ds$

This is the well known Minkowski's equation, a quadratic in four coordinates or dimensions

2 As a first approximation it follows from  $c_1 = c \sqrt{1 - \frac{v^2}{c^2}}$  that  $v$  can never be greater than  $c$ , for in that case the value of  $c_1$  would become imaginary. Hence as a first approximation the velocity  $c$  is the maximum attainable

It has already been seen that as a first approximation the velocity of light is absolute as  $v = c$  when  $v'$  is put equal to  $c$  in  $v = \frac{v' - u}{1 - \frac{v'u}{c^2}}$ .

3 As a second approximation the formula is  $\tan \alpha = \frac{v}{c}$

$$\begin{aligned} \text{and so} \quad c_1 &= c \cos \alpha = \frac{c}{\sqrt{1 + \frac{v^2}{c^2}}} \\ &= c \sqrt{1 - \frac{v^2}{c^2} + \frac{v^4}{c^4} - \text{etc.}} \end{aligned}$$

It is also clear that there is nothing absurd in  $v > c$ ; that would merely reduce the value  $c_1$  still more

If  $v = c$ , then  $c_1 = \frac{c}{\sqrt{2}}$ . Hence the effective path makes an angle of  $45^\circ$ .

If  $v > c$ , then the angle  $\alpha$  is greater than  $45^\circ$  and tends to  $90^\circ$  as  $v$  tends to  $\infty$ . Hence any velocity up to  $\infty$  is permissible and is in fact a perfectly legitimate possibility.

4. The physical explanation is that the direction of propagation is shifted forwards and so the effective velocity is diminished to its component  $c \cos \alpha = c \cos \left( \sin^{-1} \frac{v}{D} \right) = c \sqrt{1 - \frac{v^2}{D^2}}$  nearly. The interval  $ds$  is nothing but  $c_1 dt$ , i.e.,  $c \cos \alpha dt$ , the projection of the distance travelled by light. The anomaly has crept in because of assuming that time is a fourth co-ordinate with the unit  $\sqrt{-1}$ . By using an artificial fourth dimension, time has been welded into space, and made wholly imaginary, and space itself altogether illusory and fantastic.

## SECTION VI

## FRESNEL'S CONVECTION FORMULA

1. From the formula (23.11) for the addition of velocities

$$v = \frac{v' - u}{1 - \frac{v'u}{D^2}},$$

we can easily deduce Fresnel's convection formula by putting  $c'_1$  for  $v$ ,  $c_1$  for  $v'$ ,  $c$  for  $D$  and  $\frac{c_1}{c} = \frac{1}{\mu}$ , where  $c'_1$  and  $c_1$  are the velocities of light in moving and stationary water, and  $u$  is the velocity of water

$$\begin{aligned} \text{Then } c'_1 &= (c_1 - u) \left( 1 + \frac{c_1}{c^2} u \right) \text{ nearly} \\ &= (c_1 - u) \left( 1 + \frac{1}{\mu} \frac{u}{c} \right) \\ &= c_1 - u \left( 1 - \frac{1}{\mu^2} \right). \end{aligned}$$

The motion of the earth is neglected because it is the same in both the cases

2. A higher approximation can be deduced from the formula

$$\begin{aligned} v &= \frac{(v' - u) \left( 1 + \frac{v'}{D} - \frac{u}{D} \right)}{\left( 1 + \frac{v'}{D} \right) \left( 1 - \frac{u}{D} \right)} \\ \text{as } c'_1 &= \frac{(c_1 - u) \left( 1 + \frac{c_1}{c} - \frac{u}{c} \right)}{\left( 1 + \frac{c_1}{c} \right) \left( 1 - \frac{u}{c} \right)} = (c_1 - u) \frac{1 + \mu - \frac{u}{c}}{\left( 1 + \mu \right) \left( 1 - \frac{u}{c} \right)} \end{aligned}$$

3 Hoek's and Fizeau's experiments and all other experiments involving an addition of velocities can be explained in a similar way

## SECTION VII

### MICHELSON AND MORLEY'S EXPERIMENT

1 If the velocity of light is not independent of its source, then light behaves like a material particle and Michelson's experiment is easily intelligible, as was shown in Chapter II, Section VI, p 32 The effect is then really null, and it will be absolutely impossible to find out the velocity of the earth by any experiment with light produced on the earth

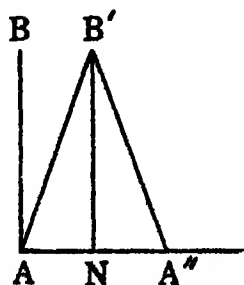
If de Sitter's test of the Binary Stars and Majorana's Moving mirrors experiment be right, and the velocity of light is independent of its source, like that of gravitons, as has been assumed in this chapter throughout, then the effect is not null, but of a very small order

2 It has been wrongly supposed in Relativity that length contracts in the direction of motion and that  $t_1 + t_2$ , the time taken in the double

journey instead of being equal to  $\frac{l}{c+v} + \frac{l}{c-v} = \frac{2lc}{c^2-v^2}$  is  $\frac{2cl}{c^2-v^2} \sqrt{1-\frac{v^2}{c^2}}$ .

If length were to contract along the path of light then, there ought to be a corresponding contraction along  $AB'$  and  $B'A''$  as well. These lengths would diminish in the ratio

$$\sqrt{1-\frac{1}{c^2}\left(\frac{v}{c}-v\right)^2} = \sqrt{1-\frac{v^2}{c^2}}$$



The assumption in Relativity that a right-angled triangle consisting of a solid sheet  $B'NA$  can move in the direction of  $AN$  with velocity  $v$  in such a way that  $B'N$  does not change, angle  $B'NA$  does not change, the side  $AN$  contracts to  $AN \sqrt{1-\frac{v^2}{c^2}}$  and yet side  $AB'$  contracts to

$AB' \sqrt{1-\frac{v^2}{c^2}}$  while  $AB'$  does not rotate and  $B'$  remains the common point of  $AB'$  and  $NB'$ , is an utterly impossible hypothesis, for there is no reason why  $AB'$  should rotate unsymmetrically round one end  $B'$  only.

3. Really the whole time taken is  $t_1 + t_2 = \frac{2l}{c^2 - v^2} = \frac{2l}{c} \left( 1 + \frac{v^2}{c^2} \right)$  nearly.

It is also the fact that light along  $AB'$  when received at  $B'$ , which is moving with velocity  $v$  is shifted forward by an angle  $\sin^{-1} \frac{v}{c}$  owing to the principle of aberration as previously explained and behaves as if it came along  $A_1B'$  where  $AB'A_1 = \alpha$ .

If, therefore, the eyepiece remains fixed so as to receive only the light coming along  $AB'$ , the component of the velocity of light along  $AB'$  is reduced to  $c_1 = c \cos \alpha = c \sqrt{1 - \frac{v^2}{c^2}}$ . It is this component which is reflected and travels along  $B'A''$ . Hence the time taken is given by  $c_1^2 t^2 = l^2 + v^2 t^2$ .

$$\text{Therefore } 2t = \frac{2l}{\sqrt{c_1^2 - v^2}} = \frac{2l}{\sqrt{c^2 - 2v^2}} = \frac{2l}{c} \left( 1 + \frac{v^2}{c^2} \right) \text{ nearly}$$

which is exactly the same as before

As it is only the apparent direction of light that is perpendicular, the factor has been taken as  $\sqrt{1 - \frac{v^2}{c^2}}$ . But  $\frac{1}{\sqrt{1 + \frac{v^2}{c^2}}}$  would also give

practically the same result.

4 The experiment does not really give a null result, but the result is too small and the difference  $= \frac{2lc}{c^2 - v^2} - \frac{2l}{\sqrt{c^2 - 2v^2}} = \frac{-l}{c} \frac{v^4}{c^4}$  nearly, which is not detectable

Miller's<sup>21</sup> observation that there is a definite drift of about 7 km. a second does not appear to be correct

5 In all experiments in which a displacement of the interference fringes is observed, both the rays of light, before they split up, are travelling in a common direction, and after reflections and refractions they both again travel in another common direction. Hence they both experience a rotation, which is exactly the same fraction or multiple of  $2\pi$ , even though in opposite senses, and so the effect of the motion of the earth is nullified. It is, therefore, no wonder that a rotation of the apparatus, which makes both the rays rotate through the same angle, makes no practical difference.

## SECTION VIII

## BUCHERER'S EXPERIMENT

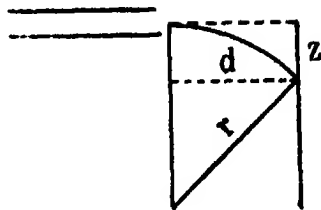
(See Saha's Modern Physics, \*\* pp 69—71.)

1 The electron with the maximum deflection travels along a circular path where

$$r^2 = (r-z)^2 + a^2$$

and 
$$\frac{mv^2}{r} = H e v$$

Hence 
$$\frac{e}{m} = \frac{2v}{H} \frac{s}{a^2 + z^2} \quad \dots \quad (23.2)$$



Experiments show that when  $\frac{v}{c}$  changes, the value  $\frac{e}{m}$  does not remain constant, unless it is multiplied by a factor nearly equal to  $\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

Accordingly the conclusion is drawn that the mass  $m_0$  has changed in the ratio  $m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$ , which is supposed to verify the result in Special

Relativity approximately

2 But the magnetic force takes time, say  $\frac{1}{D}$  seconds to act, and so can be represented by a field of flow with the velocity  $D=c$  of electric waves

The component of the magnetic field parallel to the direction of the motion of the electron does not produce any force whatsoever along that direction, the only effective component is that perpendicular to the path. Further, the maximum deflection is given by the electron making an angle  $\frac{\pi}{2}$  with the effective direction.

Now the effect of the principle of aberration, for electrons emerging apparently perpendicular to the field, is to shift the direction of the field forward by an angle  $\sin^{-1} \frac{v}{c}$ . Accordingly the component of the effective force perpendicular to the path of the electron instead of being  $e v H$  becomes

$$e v H \cos \left( \sin^{-1} \frac{v}{c} \right) = e v H \cdot \sqrt{1 - \frac{v^2}{c^2}}.$$

Hence  $\frac{e}{m} = - \frac{2v}{H \sqrt{1 - \frac{v^2}{c^2}}} \frac{z}{a^2 + z^2}$ , agreeing with the experi-

mental results

3 It is now obvious that the mass of the electron does not really change with its velocity, but the direction of the field acting upon it is changed, so that the effective component is diminished

4 For higher approximations, the corrections must include (i) the angle made by the electron with the real direction, (ii) the curved motion of the electron, (iii) its spin, (iv) finiteness of the solenoid, producing a non-uniform field, (v) variability of the current, (vi) the edge effect at the point where the electron leaves the discs, (vii) the ordinary potential of the magnetic field must also be replaced by the vector potential  $A = \left[ \frac{e v}{c r} \right]$  where the square brackets mean that the retarded potential at time  $\left( t - \frac{r}{c} \right)$  should be taken into account (See LIVEN'S<sup>23</sup> The Theory of Electricity, p 504, § 566) These considerations will be applied in a later chapter.

#### SECTION IX

##### SOMMERFELD'S FINE STRUCTURES OF SPECTRAL LINES

Niels Bohr assumes that there are several levels of energy, which an electron in its motion can occupy. If the orbit of an electron were not to rotate, then the energy, whether the orbit be circular or elliptical, would be the same, and the fall from one or the other kind of orbit would yield the same difference of energy so long as the major axis is equal to the radius of the circle. Hence the frequency of the emitted radiation from all atoms, no matter in what kind of orbits they are moving, when brought to a focus through a lense, would show one single spectral line. On the other hand, if the elliptical orbits were to rotate and their rotations be dependent on their eccentricities, and circular orbits of course do not rotate, there would be a difference in the energies due to the rotations of the elliptical orbits. Then the differences of energy due to a fall from one elliptical orbit would not be the same as that from another with a different eccentricity, although the major axis be the same. Accordingly the spectral line instead of being a single line would have fine structure. This is actually observed.

Sommerfeld<sup>24</sup> has tried to explain this phenomenon by applying the formula for the increase of mass with velocity in Special Relativity, when an electron goes round in its orbit. The assumption that the

change in Kinetic energy is due to the increase of the longitudinal mass breaks down in the case of the perihelion of Mercury, where the transverse mass also cannot be neglected.

The obvious explanation, however, is that instead of the mass changing from time to time, the force exerted by the nucleus on the electron has different effective components on the electron, depending on its tangential velocity for the time being, the effective direction of the force is shifted forward by the angle  $\tan^{-1} \frac{v}{D}$ . The problem then becomes identical with that in Chapter I, Section V, p. 8, the mass  $M$  of the Sun will correspond to the charge  $(Ze)$  on the nucleus, and the mass  $m$  of a planet will correspond to the charge  $e$  on the electron, and the constant of gravitation will be replaced by unity.

But as the velocity of the electron is now comparable to that of light  $\frac{1}{D} \frac{rd\theta}{dt}$  is not so small a quantity as to justify the neglect of all its higher powers so that  $\left( \frac{1}{D} \frac{rd\theta}{dt} \right)^2$  must now be retained in the equations on page 9 of Chapter I.

The constants of integration will be fixed by modified quantum conditions, with the help of

### The Third Universal Principle

When a force travelling with a finite velocity  $D$  acts on a thin spherical shell of radius  $a$ , spinning with an angular velocity  $\omega$  round an axis through its centre perpendicular to the force, the effect is to decrease or increase its spin according as the force is repulsive or attractive, but always to decrease the component of the force along the diameter by the

factor 
$$\frac{1}{\sqrt{1 + \frac{a^2 \omega^2}{D^2}}}$$

### References

- 1 Eddington *Theory of Relativity*, p. 29
- 2 Eddington *The Expanding Universe*, p. 16
- 3 Eddington *loc cit* pp. 16–17
- 4 Macmillan *Nature*, Jan. 16, 1923
- 5 Eddington *Theory of Relativity*, p. 168
- 6 Eddington *loc cit* p. 165
- 7 Eddington *The Expanding Universe*, pp. 54–5.
8. Banerji, A. C. *Nature*, Vol. 133, p. 984, June 30, 1934.
- 9 Eddington *Time, Space and Gravitation*, p. 108.



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- 13 Mc Crea *The Observatory*, Vol LVI, July, 1933, No 710, pp 223-4
- 14 Eddington *The Expanding Universe*, p 90
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- 17 Eddington *Nature of the Physical World*, pp 58-9
- 18 Shapley, H *Monthly Notices*, Vol 94 No 9, 1934, p 813
- 19 Einstein *Electrodynamics of Moving Bodies*, p 4
- 20 Max Born *Relativity*, pp 208, 209 and 228
- 21 Miller, D C *Rev Mod Physics*, July, 1933
- 22 Saha, M N *Modern Physics*, pp 69-71
- 23 Livens *Theory of Electricity*, p 504 § 566
- 24 Saha, M N *Modern Physics*, pp 341-6

## APPENDIX TO CHAPTER I

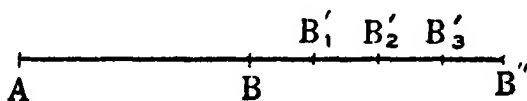
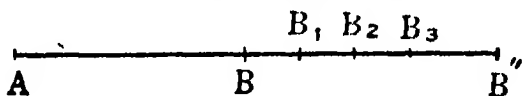
### Motion of two bodies in their line of centres

In paragraph 2 of Section IV in Chapter I (p 7), it was pointed out that as the gravitons, instead of overtaking B at the distance  $r$ , overtake it at distance  $r + \delta r$ , the intensity of the force is reduced in the ratio  $\left(1 + \frac{\delta r}{r}\right)^2$

The following is the more detailed Mathematical deduction of the same

(1) *When only one body is moving*

Suppose that gravitons leave the Sun A at infinitesimal intervals  $dt$ , and overtake the moving planet B at the further *additional* distances  $\delta r_0, \delta r_1, \delta r_2$  etc



Then for the graviton which leaves A at  $t=0$ ,

$$\delta r_0 = \frac{r}{D-v} v \quad (24.1)$$

$$\text{So the total distance } AB'' = r + \delta r_0 = r + \frac{r}{D-v} v = \frac{r}{1 - \frac{v}{D}} \quad \dots (24.2)$$

For the graviton which leaves at  $t=dt$

$$\delta r_1 = \frac{r+vd t}{D-v} v \quad \dots \dots \dots (24.3)$$

and therefore  $AB'_1 = r + vdt + \delta r_1$

$$\begin{aligned}
 &= (r + vdt) + \frac{r + vdt}{D - v} v \\
 &= (r + vdt) \frac{1}{1 - \frac{v}{D}} \quad \dots \quad (24.4)
 \end{aligned}$$

For the graviton which leaves at  $t = 2dt$

$$\delta r_2 = -\frac{r + 2vdt}{D - v} r$$

and therefore  $AB'_2 = r + 2vdt + \delta r_2$

$$= (r + 2vdt) \frac{1}{1 - \frac{v}{D}} \quad \dots \quad (24.5)$$

etc, etc, etc

Newton supposed that successive impulsive pulls at  $B_1, B_2, B_3$  etc are  $\frac{m\mu dt}{r^2}$ ,  $\frac{m\mu dt}{(r + dr)^2}$ ,  $\frac{m\mu dt}{(r + 2dr)^2}$ , etc.

But the effective impulsive pulls really act at  $B'_1, B'_2, B'_3$  etc and are  $\frac{m\mu dt}{(r + \delta r_0)^2}$ ,  $\frac{m\mu dt}{(r + vdt + \delta r_1)^2}$ ,  $\frac{m\mu dt}{(r + 2vdt + \delta r_2)^2}$  etc,

$$\begin{aligned}
 &\text{i.e., } \frac{m\mu dt \left(1 - \frac{v}{D}\right)^2}{r^2}, \frac{m\mu dt \left(1 - \frac{v}{D}\right)^2}{(r + vdt)^2}, \frac{m\mu dt \left(1 - \frac{v}{D}\right)^2}{(r + 2vdt)^2}, \text{ etc} \\
 &\text{or } \frac{m\mu dt \left(1 - \frac{v}{D}\right)^2}{r^2}, \frac{m\mu dt \left(1 - \frac{v}{D}\right)^2}{(r + dr)^2}, \frac{m\mu dt \left(1 - \frac{v}{D}\right)^2}{(r + 2dr)^2} \text{ etc.} \quad (24.6)
 \end{aligned}$$

But  $vdt$  is an infinitesimal quantity, while  $\delta r$  is finite, also  $n vdt$  is finite, if a small distance be considered. Hence the displacement decreases all the effective impulses in the ratio  $\left(1 - \frac{v}{D}\right)^2$

But the decrease in frequency due to the Doppler effect is  $= \frac{1}{1 + \frac{\delta r}{r}} = 1 - \frac{v}{D}$

$$\text{Hence the total decreased ratio} = \left(1 - \frac{v}{D}\right)^3 \quad \dots \quad (24.7)$$

(2) *When both the bodies are moving.*

Let A and B move in the same direction with velocities  $u$  and  $v'$ . Then on the Doppler principle, the frequency of the gravitons is changed in the ratio

$$\frac{1 - \frac{v'}{D}}{1 - \frac{u}{D}} \quad (24.8)$$

Hence instead of the Newtonian law of gravitation  $-F = G \frac{Mm}{r^2}$

$$\text{the effective law is nearly } -F = G \frac{Mm}{r^2} \times \frac{1 - \frac{v'}{D}}{1 - \frac{u}{D}} \times \left\{ 1 - \frac{v' - u}{D} \right\}^2 \quad (24.9)$$

$$= \left( 1 - \frac{v'}{D} \right) \left( 1 + \frac{u}{D} \right) \left( 1 - \frac{v' - u}{D} \right)^2 \quad (24.10)$$

$$= 1 - \frac{3v}{D} \text{ nearly} \quad (24.14)$$

where  $v$  is the relative velocity between the two bodies.

This embodies the **Fourth Universal Principle**, already applied in Chapter I Sections IV and V, on the sole assumption that, irrespective of any physical theory of gravitation, whether of emission or absorption of gravitons, the influence of gravitation is propagated outwards with a finite velocity.

NOTE—While the last proofs are being corrected, Prof. M. N. Saha, D.Sc., F.R.S., to whose encouragement I owe much, has kindly drawn my attention to a recent paper of P. Jordan (*Zeitschrift für Physik*, **93**, 464, 1935) in which he alludes to the possibility of the existence of gravitational quant. A physical theory of gravitons was published by me in September 1933, and a mathematical theory in July 1934.

## REMARKS BY PROF. A. C. BANERJI

*Allahabad, January 31, 1935*

I have great pleasure in congratulating Sir Shah Muhammad Sulaiman for his accuracy in the mathematical working out of his theory in which I could not find any flaw. If any criticism is to be made, it can only be levelled against the assumptions he has made. The champions of the theory of Relativity emphasise the fact that it is one comprehensive theory which has been able to explain several phenomena that cannot be explained by Newtonian Mechanics. We have yet to see whether Sir

Shah Muhammad's theory has got this comprehensive nature or whether it is a set of disconnected assumptions giving separately individual results which may otherwise be deduced from the theory of Relativity. Moreover, if his theory is to replace the theory of Relativity, his assumptions should be as few, if not fewer, and simpler than those made in the theory of Relativity. Further, from his theory it should be possible to obtain all those results got already by Relativity, and, if possible, his theory should be able to explain some other phenomena which cannot be explained by Relativity.

If I understand rightly, Sir Shah Muhammad's assumptions are so far the following —

(\*) Gravitational effect and all other physical effects (electric and magnetic) are propagated with a finite velocity

(\*\*) The law of gravitational attraction between two bodies relatively at rest is different from the law of attraction between the same two bodies when in motion relatively to each other

(\*\*\*) The theory of self-acceleration as deduced from the assumption that the velocity of gravitons or light corpuscles in space is independent of that of its source.

(iv) The theory of self-acceleration

In my opinion these ideas are at least as extraordinary as those in Relativity. Moreover, his theory of self-acceleration seems to me to be quite extraordinary. He takes the case of a spherical body moving with a velocity  $V$  along a straight line. He assumes that at least tiny light particles are radiating normally with velocity  $D$  which is about the velocity of light. He further assumes that dynamically the resultant effect of every particle in a sphere emanating corpuscles is practically the same as if the whole emission of corpuscles were from the entire mass concentrated at the centre and hence the motion is wholly radial. As his gravitons are the cause of gravitation they are not material particles subject to gravitation. He takes the absolute velocity of any such particle when it emerges to be wholly radial. It has momentum  $\mu D$  in space and had momentum  $\mu V \cos \theta$  at the centre before emerging and so it takes away momentum for  $\mu D - \mu V \cos \theta$  from the body as it emerges. These are *new* assumptions combining Newton's and Einstein's conceptions, and they contravene classical Mechanics in as much as cross-radial momentum is not taken account of. It is an uncommon assumption for a material particle. It is yet to be seen how his theory of self-acceleration would work out in the case of unsymmetrical bodies and bodies of irregular shape.

Validity of his rotational theory of light can only be judged when it is mathematically worked out. His formula for the composition of velocities is very interesting and is based on the approximate absolute-ness of the velocity in a *to and fro* journey. He has tried to deduce physical explanations of the factor in Lorentz transformations from his assumption that all effects take time to act. For velocities which are small compared with the velocity of light the analogous formula in Relativity becomes a second approximation to his formula.  $\alpha$  and  $\beta$  particles have velocities comparable to that of light, and by performing experiments with these particles it is for the physicists to test which of the two formulæ will give results in accordance with observation.

# THE ABSORPTION SPECTRA OF THE VAPOURS OF SULPHUR MONOCHLORIDE AND THIONYL CHLORIDE AND THEIR CONSTITUTIONS

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Communicated by Prof M N Saha

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It is well known that chemical constitution of compounds containing one or more atoms with multiple and variable valency can be represented by a number of different formulæ. An example is afforded by sulphur monochloride for which two constitutional formulæ have been proposed, *viz.*,  $\text{Cl-S-S-Cl}$  and  $\text{S=S-Cl}_2$ . There is no such ambiguity in the case of analogous substance obtained by the substitution of oxygen for one of the sulphur atoms, *viz.*, thionyl chloride for which the formula  $\text{O=S-Cl}_2$  is accepted by everybody. The reasons for this divergence of view will be apparent from the following quotation from Mellor's *Comprehensive Treatise on Theoretical and Inorganic Chemistry*, Vol X, page 642 "Its constitutional formula may be  $\text{Cl-S-S-Cl}$  or according to A Michaelis and O Schifferdecker, H L Olin, L Carius and T E Thorpe,  $\text{S=S-Cl}_2$ , analogous with thionyl chloride  $\text{O=S-Cl}_2$ , and it has accordingly been called sulphothionyl chloride. B Holmberg said that its action on mercaptan favours the formula  $\text{Cl-S-S-Cl}$ . According to G Brunl and M Amadori, just as a series of persulphides is produced by the introduction of sulphur to hydrogen sulphide  $\text{H-S-H}$ ,  $\text{H-S}_2\text{-H}$  and  $\text{H-S}_n\text{-H}$ , so may the corresponding sulphur chlorides, sulphur dichloride  $\text{Cl-S-Cl}$ , sulphur monochloride  $\text{Cl-S}_2\text{-Cl}$  and  $\text{Cl-S}_n\text{-Cl}$  be possible."

I have tried to solve this problem by studying the absorption spectrum of the vapours of sulphur monochloride and thionyl chloride. Very little work of this nature has previously been done on these compounds. Lowry and Jessop<sup>1</sup> found that sulphur monochloride is transparent to light of wavelengths  $5200\text{\AA}$  and  $5400\text{\AA}$ . They found that it has a strong maximum absorption in the ultraviolet,  $\log \epsilon$  being 3.8 at  $2660\text{\AA}$ , but it

could not be estimated photometrically on account of the absorption of ultraviolet light by the dichloride. In the present case the experiment was done in such a way that no trouble could arise by the presence of dichloride as was the case in Lowry and Jessop's experiment.

### EXPERIMENTAL PROCEDURE

Both the substances are liquids. Their properties are given below.

Sulphur monochloride					Thionyl chloride
A yellowish red heavy liquid, fumes in air, its boiling point is 138°C. Its vapour pressure in mms of mercury at various temperatures is					A colourless liquid boiling at 80°C, when heated it dissociates into SO <sub>2</sub> , sulphur monochloride and chlorine.
	0°C	10°C	20°C	40°C	
	3.7	6.4	10.7	28.0	

Both of the substances taken were Merck's extrapure samples. The absorption chamber was a pyrex glass tube one centimetre in diameter having a length of two metres. The two ends of the tube were closed with quartz windows which were fixed on to the ground ends of the tube by means of liquid sodium silicate. The liquid under investigation was kept in a bulb which was connected through a stopcock to the absorption chamber by means of a side tube. The absorption tube was connected by means of a side tube and stopcock to a pump which was kept running continuously. The pressure of the vapour inside was measured by means of a manometer. The continuous running of the pump served the purpose of maintaining a constant current of the vapours passing through the absorption vessel, the rate being regulated by means of the stopcocks. The vapour within the absorption chamber was kept successively at the various values (<0.1, 0.1, 2, 5, 7, 10 mms of Hg). This circulation ensured that all the products of any dissociation that may have taken place (there was very little possibility that any dissociation had taken place, as the temperature of the vessel was not greater than 17°C, at this temperature the dissociation is negligible for either of the two substances) in the absorption chamber will be drawn out and will not vitiate the experimental results.

For the source of continuous radiation a hydrogen tube run by a 2 K. W. transformer was used. Photographs were taken with a quartz E<sub>2</sub> spectrograph. Ilford special rapid plates sensitised by means of Nujol

paraffin were used for photographing the spectra. This treatment made the plates sensitive right up to 1850 Å. A copper arc was used as a standard.

### RESULTS AND DISCUSSION

The results of this investigation are as follows.

1. The absorption spectrum of sulphur monochloride shows two regions of continuous absorption when the pressure of the vapour in the absorption chamber was 0.1 mm of mercury or even less. In between there was a patch of retransmitted light. As the pressure of the absorbing vapour increased the intensity of the retransmitted light gradually diminished till at a pressure of 2 mm. there was no retransmitted light and the two regions of continuous absorption merged into one. As the pressure of the vapour increased the long wavelength limit of the regions of absorption went on receding towards the red, till it adopted a stationary position at a pressure of 5 mm. With further increase of the pressure of the absorbing vapour there was no change in the position of the long wavelength beginning. This shift with increasing pressure of the vapour was found even when the two regions of absorption had not merged into one, and the difference between their long wavelength beginnings was practically the same throughout that range of pressure for which the two regions were distinctly separate.

The long wavelength beginnings of the two regions of absorption were  $2740\text{Å} = 104.3\text{ Kcals}$  and  $2135\text{Å} = 134\text{ Kcals}$  respectively with the vapour at about 0.1 mm pressure. When the two regions merged into one, the long wavelength beginning of the absorption of the vapour at 5 mm. or more is  $4290\text{Å} = 66.6\text{ Kcals}$ .

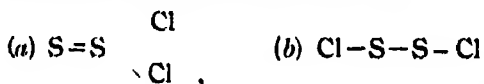
All the cuts are fairly sharp. The beginning of absorption was determined from the microphotograms of the spectra. In this connection the author would like to thank Prof. Ashutosh Mukerji of Patna for having kindly allowed the use of the microphotometer belonging to Science College, Patna.

2. In the case of thionyl chloride, too, there were two regions of continuous absorption separated by a retransmitted patch of light. The absorption spectrum was photographed when the pressure of the vapour inside the chamber was very small ( $< 0.1\text{ mm}$ ). In one of the photographs certain absorption bands appeared along with the continuous absorption. As the pressure of the vapour was increased the two regions of continuous absorption pushed further towards the red end of the plate, till it became stationary at a pressure of 7 mm. The difference between

the beginnings of the two regions was roughly the same as they shifted towards red with increasing pressure

The bands were extremely faint and their heads were not clearly developed. Their measurement was, therefore, extremely difficult and there is, consequently, a good deal of uncertainty in locating their positions. The various heads were at  $\lambda$  2107, 2099, 2086, 2076, 2067, 2047. These bands could be identified as those of CO. It must have come up as an impurity from the grease applied to the stopcock. The long wavelength beginnings of the two regions of continuous absorption were  $\lambda$  2980 and 2040 when the pressure of the gas was less than 0.1 mm of Hg. When the pressure was 7 mm the long wavelength beginning of the region of continuous absorption was 3215 Å.

Coming to the interpretation of these results we see that sulphur monochloride is, according to the majority of the chemists, represented by either of the two constitutional formulæ



In (a) one of the sulphur atoms is taken to be divalent and the other as quadrivalent. Let us first consider the optical dissociation of

$\text{S}=\text{S} \begin{array}{c} \text{Cl} \\ \diagdown \\ \text{Cl} \end{array}$ . The light dissociates the molecule into either S and  $\text{SCl}_2$ , or  $\text{S}_2\text{Cl}$  and Cl. In the first alternative, the two regions of continuous absorption correspond to dissociation into  $\text{SCl}_2$  and S in its  $^3\text{P}$  and  $^1\text{D}$  states respectively. In the second alternative the two regions are due to the two different electronic states of  $\text{SCl}_2$  molecule as the  $^3\text{P}$  states of chlorine are too near to one another to give two different regions of continuous absorption. The first alternative can be tested. The second one cannot, however, be tested for want of data.

We can calculate thermochemically the energy of dissociation of  $\text{S}_2\text{Cl}_2$  into S and  $\text{SCl}_2$  as follows

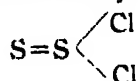
- (1)<sup>2</sup>  $2 [\text{S}]_{\text{rhombic}} + \text{Cl}_2 = \text{S}_2\text{Cl}_{2,\text{liq}} + 14.5 \text{ Kcals}$
- (2)<sup>3</sup>  $\text{S}_2\text{Cl}_{2,\text{liq}} + \text{Cl}_{2,\text{gas}} = 2 \text{SCl}_{2,\text{liq}} + 9.8 \text{ Kcals}$
- (3)<sup>4</sup>  $\text{S}_2\text{Cl}_{2,\text{liq}} + 8.5 \text{ Kcals} = \text{S}_2\text{Cl}_{2,\text{gas}}$
- (4)<sup>5</sup>  $2 [\text{S}]_{\text{rhombic}} + 29.3 \text{ Kcals} = \text{S}_{2,\text{gas}}$
- (5)<sup>6</sup>  $\text{S}_{2,\text{gas}} + 102.6 \text{ Kcals} = 2 \text{S}_{\text{gas}}$
- (6)<sup>7</sup>  $\text{SCl}_{2,\text{liq}} + 4 \text{ Kcals} = \text{SCl}_{2,\text{gas}}$

We can very easily calculate from the above the energy required to dissociate  $\text{S}_2\text{Cl}_2$  into S and  $\text{SCl}_2$ . It amounts to 63.8 Kcals. The



long wavelength beginning of the region of continuous absorption, which has been taken to give the energy of dissociation of the molecule for many compounds by various workers, amounts to 66.6 Kcals. The values are in very nice agreement. This shows our assumption, that  $S_2Cl_2$  dissociates into S and  $SCl_2$ , to be valid. This is further substantiated by the presence of two regions of continuous absorption at very low pressures of the vapour. The difference between their beginnings amounts to  $134 - 104.3 = 29.7$  Kcals. The value of  $^3P - ^1D$  for sulphur has been found to be about 26 Kcals<sup>8</sup>. This agreement is very nice and confirms our view.

If the molecule  $S_2Cl_2$  breaks up optically into S and  $SCl_2$ , its constitution cannot be represented by any other formula but the following

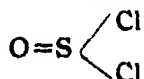


and it does not dissociate optically in any other way but the above-mentioned

Coming to  $SOCl_2$ , we find that it behaves in an exactly analogous manner. Unfortunately we cannot calculate, for want of data, the energy required to dissociate the molecule into O and  $SCl_2$ , or S and  $OCl_2$ ,

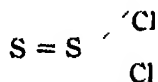
depending upon whether the molecule is  $O=S \begin{cases} \text{Cl} \\ \text{Cl} \end{cases}$  or  $S=O \begin{cases} \text{Cl} \\ \text{Cl} \end{cases}$ ,

thermochemically. The only data we know is that the heat of formation of liquid thionyl chloride is 47.2 Kcals per mol and its heat of vaporisation is 54.45 cals per gram. These are insufficient to calculate the required energy. We rely on the interpretation of the two regions of absorption and to infer therefrom the constitution of the molecule. The difference between the long wavelength beginning of the two regions of continuous absorption is  $140 - 96 = 44$  Kcals. This agrees well with the difference between the energies of  $^3P$  and  $^1D$  states of oxygen, which is equal to 1.9 volts<sup>9</sup>. This shows that the molecule of thionyl chloride has the structure



and dissociates into O ( $^3P$ ,  $^1D$ ) and  $SCl_2$ . Fortunately the chemists do not advance any other alternative formula for this molecule and the spectroscopic observations substantiate their observations regarding the constitution of thionyl chloride. In the case of sulphur monochloride,

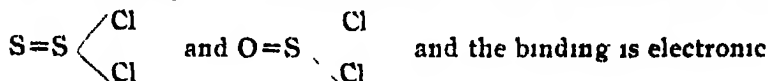
however, the spectroscopic result confirms the view that the constitution can be represented as



It further shows that the binding between S and S in the monochloride and between O and S in the thionyl chloride is electronic, a view which has already been put forward by Prideaux<sup>10</sup> for the latter case

### SUMMARY

Absorption spectra of sulphur monochloride and thionyl chloride was studied. Both the substances show, at low pressures, two regions of continuous absorption separated by a region of retransmission. Their long wavelength beginnings are at 2740 Å and 2135 Å in the case of  $\text{S}_2\text{Cl}_2$ , whereas for  $\text{SOCl}_2$ , they were at 2980 Å and 2040 Å. The long wavelength beginning shifts towards red with increasing pressure. The difference between the energies corresponding to these beginnings is equal to that of  $^1\text{P}-^1\text{D}$  of S in the case of  $\text{S}_2\text{Cl}_2$  and  $^3\text{P}-^1\text{D}$  of O in the case of  $\text{SOCl}_2$ . It is shown that the constitution of these molecules is as



### ACKNOWLEDGMENT

I gratefully thank Prof. M. N. Saha, F.R.S., for the encouraging kindness he bestowed on me.

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## STUDIES ON THE FAMILY HETEROPHYIDÆ ODHNER, 1914

**Part I.**—On a New Distome from the Indian Fishing Eagle—*Haliacetus leucoryphus*—with Remarks on the Genus *Ascocotyle* Looss, 1899, and *Phugicola* Faust, 1920.

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The family Heterophyidæ is composed of a number of genera of small flukes which are usually parasitic in fish-eating Vertebrates. The members of this family were known to occur in only birds and mammals till 1932 when Mueller and Van Cleave enlarged the scope of the family to include certain genera which are parasitic in fishes. The family is of considerable interest in human and veterinary medicine. Because of their occurrence in birds and mammals and their normal or potential infestation of man, the Heterophyids in other countries have received serious consideration. From India, however, this is the first record of the occurrence of a member of this family.

### **Ascocotyle Looss, 1899**

Looss in 1899 created the genus *Ascocotyle* for *Distomum coleostomum* Looss, 1896, and added one more new species to it—*A. minuta*. Subsequently a number of species have been added to the genus, namely: *A. italica* Alessandrini, 1906, *A. angrense* Travassos, 1916, *A. longa* Ransom, 1920, *A. nana* Ransom, 1920, *A. diminuta* Stunkard and Haviland, 1924, *A. angeloi* Travassos, 1928, *A. felippoi* Travassos, 1928, *A. ascolongae* Witenberg, 1928, *A. arnaldi* Travassos, 1928, *A. megaloccephala* Price, 1932

and *A. puertoricensis* Price, 1932. Faust in 1920 described, from the intestine of the monkey-eating eagle, *Phagicola pithecophagicola* N Gen, N Sp "a fluke which on a restudy," by Faust in 1926 "has been found to belong to the genus *Ascocotyle* and should, therefore, be designated as *A. pithecophagicola*" In the original description of *P. pithecophagicola* Faust failed to notice the posterior oral appendage and gonotyls and the apparent absence of these structures necessitated the creation of a new genus Stunkard and Haviland in 1924 split up the genus *Ascocotyle* into two sub-genera (*Ascocotyle*) with *A. coleostomum* as type and (*Parascocotyle*) with *A. minuta* as type In his revision of the family Heterophyidae Witenberg in 1929 recognised the sub-genus (*Parascocotyle*) Stunkard and Haviland as of generic rank and provisionally included in it *Phagicola pithecophagicola* He further considered *Parascocotyle diminuta* Stunkard and Haviland as a synonym of *P. minuta* Looss, attributing the specific differences between the two species to age and fixation. A year later after examination of the type specimens of *P. pithecophagicola* Witenberg was unable to add anything to the original description of Faust He, however, suggested that only a redescription of a new material of *Phagicola pithecophagicola* could settle the question whether *Parascocotyle* is synonymous with *Phagicola* or they both are valid genera Travassos in 1930 and Price, 1933, accepted *A. (Parascocotyle) diminuta* and *A. (Parascocotyle) minuta* as valid species Recently Price (1933) has restudied the type specimens of *P. pithecophagicola* Faust and has demonstrated clearly the presence of a long posterior oral appendage, gonotyls and a globular receptaculum seminis, necessitating the identity of the genera *Phagicola* and *Parascocotyle* Nevertheless Price is still "of the opinion that sufficient differences exist between *Ascocotyle* and *Phagicola* to warrant the latter being considered as a distinct genus" *Ascocotyle plana* Linton, 1928, which Witenberg in 1928 regarded as a synonym of *Pygidioptes genata* Looss and which Travassos in 1930 regarded as a synonym of *Ascocotyle (Phagicola) angrense* Travassos, has been recognised by Price in 1933 to be a species of *Pygidioptes*: *P. plana*

### ***Ascocotyle (Phagicola) intermedius* N Sp.**

A large number of these minute distomes were obtained from the intestine of the Indian Fishing-eagle—*Haliaeetus leucoryphus* In the

living condition they are quite active and show considerable power of contraction and expansion especially in the anterior half of the body. In their natural habitat the parasites appear like tiny masses of yellowish brown pigment. Normally the body is pyriform in outline but in extended condition the sides become almost parallel while the contracted worm may be as wide as long. The dorsal lip may be extended anteriorly in the form of a triangular process or retracted into a short knob. In permanent mounts the parasite has a thin flat body with a flask-shaped outline, measuring 0.6–0.9 \* in length and 0.2–0.38 in maximum breadth across the anterior margin of the ovary. The body is uniformly studded with minute backwardly directed spines of  $0.005 \times 0.002$  size, which diminish both in number and size as they approach the posterior end.

The oral sucker is terminal, measuring 0.04–0.05 in diameter, it is surrounded by two crowns of alternating cylindrical and abruptly-pointed spines, about 28–30 in number. These spines are quickly shed when the worms are placed in normal salt solution or tap water. The spines in the anterior crown measure  $0.01–0.013 \times 0.003$  in size while those in the hinder crown measure  $0.009–0.01 \times 0.003$ . The feebly muscular acetabulum, spherical in outline and 0.066–0.077 in diameter, is situated about the middle of the body. The size ratio between the oral and the ventral suckers is as 2:3. Both the acetabulum and the genital pore lie in a shallow depression—the ventro-genital sinus—on the ventral body surface. The genital sinus or ductus hermaphroditicus opens in this depression just in front of the acetabulum. The genital opening is guarded on the anterior and posterior sides by two muscular, transversely elongated pads, lenticular in shape,—the gonotyls of Witenberg,—which measure  $0.04–0.05 \times 0.013$  in size.

The excretory pore is terminal lying at the extreme posterior end of the body. The bladder is typical of the genus and consists of a short main stem which bifurcates just behind the receptaculum seminis into two short but wide cornua.

The oral sucker has a posterior hollow, conical prolongation—the oral appendage or caecum—of  $0.04–0.05 \times 0.03$  size, which is situated on the dorsal side of the prepharynx. The prepharynx is long, measuring 0.06–0.09 in length. The muscular pharynx,  $0.03–0.04 \times 0.02–0.03$  in size, is followed by a short oesophagus of 0.03–0.08 length. The wide intestinal caeca are moderately long terminating posteriorly in level with the anterior margin of the ovary.

\* All measurements are in mm.

The gonads are well developed and lie in the posterior half of the body. The testes are situated symmetrically with their long axes directed obliquely, one on each side of the hinder end of the body. They have slightly irregular margins and measure  $0.12-0.17 \times 0.07-0.12$  in size. The vasa efferentia pass forwards and open into the posterior end of the vesicula seminalis which is enormously developed measuring  $0.38-0.42 \times 0.07$  in size. It is roughly retort-shaped with its long axis placed transversely in the space between the acetabulum and the receptaculum seminis and is narrowed anteriorly to form a fairly long tubular ejaculatory duct of  $0.1-0.12 \times 0.03$  size which lies to the right side of the acetabulum. Terminally the ejaculatory duct joins the uterus just before the genital pore forming the genital sinus. There is no cirrus sac present.

The ovary is situated a little to the right side about the middle of the post-acetabular region between the right testis and the coils of the uterus. It has an irregular outline, measuring  $0.08-0.1 \times 0.11-0.14$  in size. The receptaculum seminis, somewhat rounded in outline, lies, in the median line in level with and partially overlapping the ovary and the yolk reservoir. Its size varies with the amount of its contents ranging from  $0.08-0.13$  in length and  $0.1-0.13$  in breadth. A short but fairly wide Laurer's canal is present.

The vitellaria consisting of small irregular follicles of  $0.01-0.04 \times 0.008-0.02$  size, are profusely developed and extend laterally from the anterior level of the pharynx to the posterior ends of the testes. Anteriorly in the region from the pharynx to a little distance behind the intestinal bifurcation the vitelline follicles of the two sides meet in the median line. A small yolk reservoir lies slightly to the left of the median line between the posterior end of the vesicula seminalis and the receptaculum seminis, partly overlapping the latter.

The uterus composed of a wide S-shaped ascending coil is confined to the space between the testes and the ventro-genital sinus, never extending beyond the latter. It is packed with a fairly large number of large sized, yellowish brown, operculate eggs of  $0.03-0.035 \times 0.015-0.017$  size.

*A. intermedius* N. Sp. is assigned to the sub-genus (*Phagocola*) Travassos on account of the length of the oesophagus and of the intestinal caeca and the extent of the uterus. This species resembles the sub-genus (*Ascooecotyle*) Travassos in the arrangement of oral spines and the relatively large extent of the vitellaria but it differs from it in the

presence of a fairly long oesophagus followed by long caeca which extend far behind the acetabulum and in the extent of the uterus which never extends in front of the genital sinus, features in which it resembles *A. (Phagicola)*. It differs from all the species of the latter sub-genus in the enormous development and extent of the vitellaria and in having a double crown of oral spines. Within the sub-genus, in the arrangement of the oral spines it resembles *A. (Phagicola) angeloi* and *A. (Phagicola) nana*, in the latter species only the dorsal spines are in double row. *A. intermedius*, however, differs from all the species of the genus in the number of oral spines, much larger extent of the vitellaria and the size of its eggs which are the largest in the genus.

The genus *Phagicola* as now constituted by Price differs from *Ascocotyle* only in the presence of an oesophagus, the length of the intestinal caeca which extend posteriorly beyond the acetabulum, the post-acetabular position of the vitellaria, the extent of the uterus which never extends anteriorly beyond the ventro-genital sinus. The intermediate species described in this paper connects the two genera—*Ascocotyle* and *Phagicola*—as regards the extent of the vitellaria. The remaining important differences between the two genera are the extent of the intestinal caeca and the uterus. The extent of the intestinal caeca cannot in this case be considered of generic importance as all the gradations in their length exist between such forms as *Phagicola minuta* and *P. arnaldi*. The extent of the uterus alone does not offer a sufficient justification for maintaining two distinct genera. We, therefore, agree with Travassos in reducing the genus *Phagicola* to the rank of a sub-genus.

The diagnosis of the genus *Ascocotyle* as given by Travassos needs certain modifications in the light of the new forms described subsequently. The emended diagnosis of the genus is as follows —

Minute distomes, body thickly spinose, oral sucker armed with a single or double crown of straight cylindrical spines. Oral sucker continued posteriorly into a distinct appendage, prepharynx long, pharynx well developed and muscular, oesophagus present or absent, intestinal caeca long or short. Acetabulum median, situated in association with the genital sinus in a depression of the ventral body surface. Testes situated one on each side at the hinder end of body, vesicula seminalis and ejaculatory duct well developed. Cirrus sac is absent. Ovary median or slightly to one side, pretesticular, receptaculum seminis large, situated in level with ovary or behind it. Vitellaria lateral, usually post-acetabular sometimes extending as far forward as the pharynx.

and meeting mesially near the intestinal bifurcation Uterus usually post acetabular, rarely extending as far forwards as the pharynx; eggs large, operculate, measuring  $0.015-0.035 \times 0.008-0.017$  in size

Parasitic in birds and mammals

### Key to the Sub-genera of *Ascocotyle* Looss

- 1 Vitellaria extending in front of acetabulum,  
Uterus extending in front of ventro-genital  
sinus, Oesophagus almost absent . *Ascocotyle* (*Ascocotyle*)
- 2 Vitellaria post-acetabular, except in *A. intermedius*, Uterus confined behind ventro-genital sinus, Oesophagus well developed *Ascocotyle* (*Phagicola*)

### Key to the Species of the Sub-genus *Ascocotyle* (*Ascocotyle*)

- 1 Vitellaria extending from the level of pharynx  
to centre of acetabulum *A. (Ascocotyle) megaloccephala*
- Vitellaria confined between posterior ends of  
caeca and body ... 2
- 2 Vitellaria pretesticular *A. (Ascocotyle) coleostomum*
- Vitellaria extending into testicular region 3
- 3 Oral spines 36 in number *A. (Ascocotyle) felippei*
- Oral spines 32 in number *A. (Ascocotyle) puertoricensis*

### Key to the Species of the Sub-genus *Ascocotyle* (*Phagicola*)

- 1 Vitellaria extending from the hinder end  
up to the level of pharynx ... *A. (Phagicola) intermedius*
- Vitellaria post-acetabular ... .. 2



- |     |   |  |
|-----|---|--|
| 2   | Oral spines in double row   | 3                                      |
|     | Oral spines in single row ..  | 4                                      |
| 3   | Oral spines in double row on the dorsal side and in single row on the ventral           | <i>A. (Phagicola) nana</i>             |
|     | Oral spines in double row on both the surfaces  | <i>A. (Phagicola) angelus</i>          |
| 4   | Genital pore situated at intestinal bifurcation   | <i>A. (Phagicola) pithecophagicola</i> |
|     | Genital pore situated behind intestinal bifurcation                                     | 5                                      |
| 5.  | Intestinal caeca not reaching ovary   | 6                                      |
|     | Intestinal caeca reaching or extending beyond ovary ..                                  | 8                                      |
| 6   | Oral sucker distinctly larger than acetabulum   | <i>A. (Phagicola) angrense</i>         |
|     | Suckers about equal in size   | 7                                      |
| 7   | Oral spines 16 in number  | <i>A. (Phagicola) diminuta</i>         |
|     | Oral spines 19 (rarely 20 or 18) in number  | <i>A. (Phagicola) minuta</i>           |
| 8   | Vitellaria follicular ...   | 9                                      |
|     | Vitellaria composed of compact masses   | 10                                     |
| 9   | Vitellaria composed of 2—8 follicles on each side—Eggs 0.016—0.018 × 0.009—0.01 in size | <i>A. (Phagicola) longa.</i>           |
|     | Vitellaria composed of 9—12 follicles on each side—Eggs 0.02—0.024 × 0.01—0.012 in size | <i>A. (Phagicola) arnaldi</i>          |
| 10. | Vitellaria lateral and post-ovarian, Oral appendage and prepharynx equal in length      | <i>A. (Phagicola) ascolonga</i>        |

Vitellaria lateral extending up to or beyond  
ovary, Oral Appendage half the length of  
prepharynx ..

*A (Phagicola)*  
*italica*

This work was carried on under the guidance of Dr. H R Mehra to whom I am greatly indebted for his valuable help and advice. I am also obliged to Dr D R Bhattacharya for laboratory facilities in the Department. I am grateful to the Lady Tata Memorial Trust, Bombay, for the grant of a research scholarship for investigations in Helminthology.

#### EXPLANATION OF PLATE AND LETTERING

Plate No. I Ventral view of *Ascoctyle (Phagicola) intermedius*  
N Sp

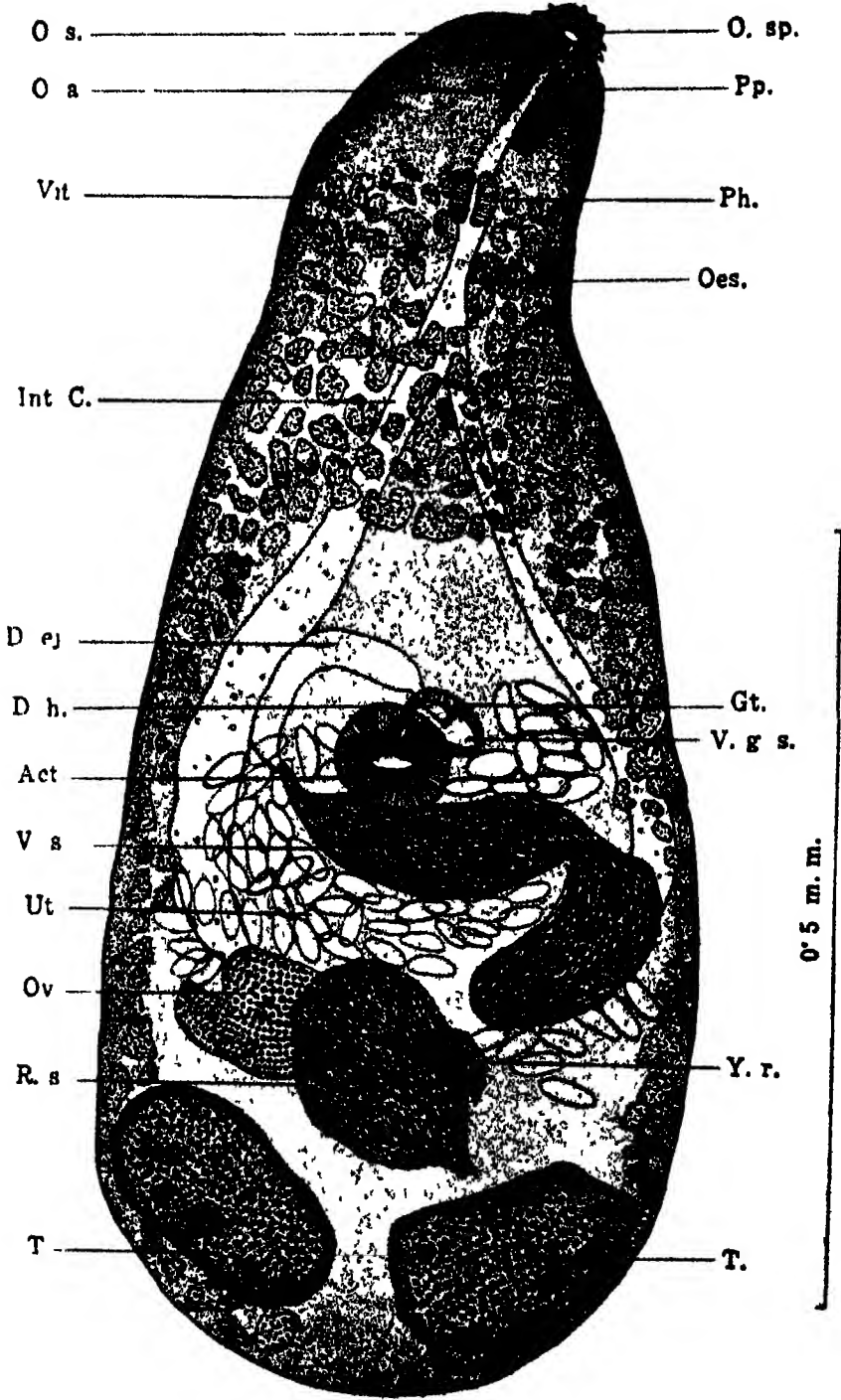
(The oral spines are not true to the magnification scale)

Act	Acetabulum		
D ej	Ductus ejaculatorius	Ph	Pharynx
D h	Ductus hermaphroditicus or genital sinus	Pp	Prepharynx
Gt	Gonotyl	R s	Receptaculum seminis
I c	Intestinal caecum	T	Testis
O a	Oral appendage	Ut	Uterus
Oes	Oesophagus	Vit	Vitellaria
O s	Oral sucker.	Y r	Yolk reservoir
O sp	Oral spines	V s	Vesicula seminis
Ov	Ovary	V g s	Ventro genital sinus

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NOTES ON A CASE OF UNILATERAL ATROPHY OF TESTIS  
IN THE COMMON WALL GECKO (*HEMIDACTYLUS*  
*FLAVIVIRIDIS* RUPPEL)

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Received August 22, 1934

While examining the gonads of a number of wall-lizards (*Hemidactylus flaviviridis* Ruppel) a specimen was found with but one testis of normal size on the left side. On careful dissection the other testis—the one on the right side—was found to consist of extremely attenuated and degenerate seminiferous tubules of microscopical size attached to the Vas deferens. The justification for describing this abnormal feature arose from the fact that on looking up the literature it was found that no case of testis deformity in lizards was on record.

The abnormality of testis has been studied by Fell (4) in a ram, by Crew and Fell (3) in a goat, a cat, a rabbit, a frog, and a human being, by Kennedy (6) in a rat, and by Bhattacharya and Das (1) in a frog. Interesting accounts of cases of hermaphroditism and diseases of the reproductive organs in animals have been recorded by Tichomrow (9) in birds and mammals, Sutton (8) in frogs, birds and mammals, and Bhaduri (2) in *Rana tigrina*. Very unusually, sixteen cases of pigeons without a discernible gonidial tissue have been found and described by Oscar Riddle (7). The absence of gonads was complete and permanent, not temporary or recent. The gonadless condition is regarded as purely developmental. In spite of the complete absence of testicular tissue the birds showed masculine behaviour.

Thus from the literature cited above it will be seen that there is no account extant of the abnormal structure of the lizard testis and I therefore take the opportunity of recording the case of atrophy of a testis in a lizard and describing the degenerate cellular structure of the organ.

The entire gonad was dissected out and fixed in Champy's chromo-osmic fixative. Sections were cut by paraffin method and stained in iron haematoxylin.

### THE HEALTHY TESTIS

The left testis showed a normal structure in every respect. The tunic investing the testis was healthy, the seminiferous tubules were large and spermatozoa were present in the lumen of each tubule. Stages of spermatozoa could be seen in sections and the organ appeared to be in active condition. The inter-tubular tissue was composed of connective tissue cells, the interstitial cells could not be distinguished. The epididymis and the vas deferens were in every way typical.

### THE DEGENERATE TESTIS

The histological study of the atrophic testis of the right side on the other hand presents several points of interest (Fig 2). In the first place the fibrous tissue beneath the investing membrane of the testis (Tunica Albuginea) has developed to a great extent in several places. The outline of the seminiferous tubules is very ill defined and the degeneration of the germinal epithelium is considerable. The lumina of the degenerate tubules were all filled with a coagulated fluid. The formation of such fluid has been observed and described by Crew and Fell (3) in the displaced and undescended testis of the goat, cat and rabbit. They have identified spherical colloid bodies in large numbers. The coagulated mass in the centre of the tubules is regarded as a degenerate product of the germinal epithelium.

The reduced size of the right testis is evidently due to its wasting away for lack of nourishment. The epididymis on the other hand shows no sign of degeneration. It is a small structure attached to the vas deferens. The internal lining of the right vas deferens is composed of normal ciliated columnar epithelial cells. There is no sign of reduction in size.

I wish to express my sincere thanks to Professor D. R. Bhattacharya for his criticisms.

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### EXPLANATION OF FIGURES

Fig 1.—The abnormal testis of the lizard (*Hemidactylus flaviviridis* Ruppel) The right testis is very small as compared with the left

Fig. 2 —Transverse section of the abnormal (right) testis

Fig 3 —A portion of the right testis under high power showing the degeneration of cells of the tubules The intercellular spaces are filled with coagulated fluid

### LETTERING

COG—Coagulated fluid in the centre of the tubules of the right testis

CON—Connective tissue beneath the investing membrane

DCT—Degenerate cells of the tubules of the right testis

DT—Degenerate tubules of the right testis

ITT—Intertubular tissue

LT—Left testis

LEPD—Left epididymis

LVD—Left Vas deferens

RT—Right testis

REPD—Right epididymis

RVD—Right Vas deferens.

TA—Tunica albuginea.

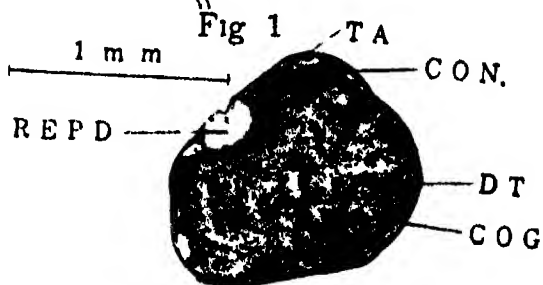
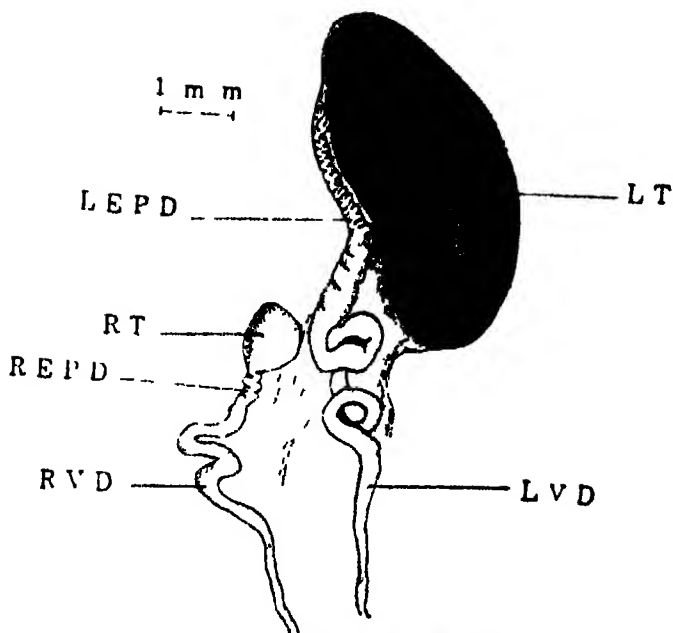


Fig. 2

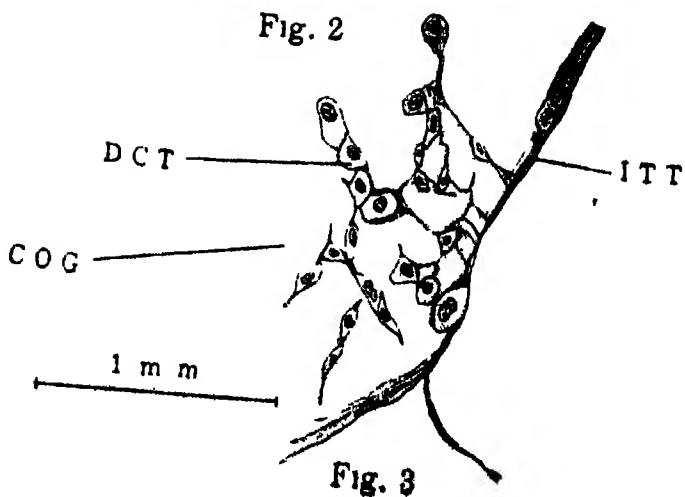


Fig. 3



ON A NEW SPECIES OF *CATATROPIS* ODHNER, 1905,  
FROM AN INDIAN FOWL—*GALLUS BANKIVA MURGHI*

BY HAR DAYAL SRIVASTAVA

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Communicated by Dr H R Mehra

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A large number of monostomes referable to *Catatropis* Odhner were obtained from the rectal caeca of the domestic fowl, *Gallus bankiva murghi*, which had died after a prolonged sickness. Besides these monostomes the bird was found on post-mortem examination to be heavily infected with *Amoebolaenia sphenoides* Railliet, 1892, and *Railhetina* (*Fuhrmannella*) *echinobothrida* Megnin, 1800. The bird exhibited marked pathological symptoms such as pronounced emaciation, anaemia, dull plumage and poor health. There was little flesh on the breast and the legs were thin and dry. The intestines were badly damaged. In addition to an enormous enlargement of the rectal caeca intestinal inflammation and puss-formation were also noticed at several places.

***Catatropis indicus* N Sp**

*Notocotyidae* is the most widely studied family amongst the monostomatous trematodes. It is in this family that we come across the earliest records of monostomes, such as *Catatropis verrucosa* Frolich, 1789, parasitic in the rectum of *Anas domestica* Frolich, 1789, and Gmelin, 1790, classified these worms as *Fasciola* while Zeder in 1800 removed them to the genus *Monostoma*. In 1839 Diesing assigned these parasites to the genus *Notocotylus* of which *N. serialis* is the type species. Odhner in 1905 recognised this earliest known monostome to be distinct from Diesing's type species and removed it to a new genus *Catatropis*.

Upto this time half a dozen species have been recorded under this genus, namely —*C verrucosa* Frolich, *C lara* Kossack, *C charadri* Scrbabin, *C filamentis* Barker, *C gallinulae* Johnston, and *C orientalis* Harshe. In the following pages I give an account of one more species of the genus.

The parasite was found in large numbers in the rectal caeca of a domestic fowl. In the living condition they have a light brown colour and show little power of contraction and expansion. The flat, transparent body, 4.2–4.6\* in length and 1.2 in maximum breadth which lies across the anterior end of the vitellaria, has smooth convex dorsal surface and an armed concave ventral surface bearing three longitudinal rows of unicellular glands which are non-protrusible. The glands in the median row are contiguous but those in the outer rows are distinct and vary from 10–12 in number in each row. The sides of the body are nearly parallel except at the ends which are bluntly rounded. The ventral surface is studded with minute backwardly directed spines, 0.008–0.01 in length and 0.002–0.003 in breadth at the base, extending between the region of the genital pore and the ovary. The ratio of the length to the maximum breadth of the body is as 4:1.

The excretory system is typical of the genus. The wide funnel-shaped bladder has its inner walls thrown into ridges forming the "Rippon" of Looss. From the anterior corners of the bladder are given off the cornua which lie laterally and give off throughout their course both internal and external branches. The excretory pore lies on the dorsal side about 0.2 in front of the posterior end.

The oral sucker is almost terminal with a spherical outline measuring 0.14–0.2 in diameter, and is followed by a 0.2–0.26 long oesophagus. Pharynx is absent. The intestinal caeca, of nearly equal length, end posteriorly about the level of the excretory pore. They are provided, throughout their course, with numerous minute diverticula and bend inwards in the region of the testes, lying between the latter and the median ovary and mehlis gland.

The deeply lobed testes, 0.75–0.99 in length and 0.2–0.3 in maximum breadth, are situated laterally near the posterior end close outside the intestinal caeca extending from the level of the mehlis gland to that of the excretory pore. The vesicula seminalis is enormously developed and lies outside the cirrus sac, extending in a characteristically coiled manner from the latter to the anterior limit of the vitellaria. The cirrus sac is

\* All measurements are in mm.

median and flask-shaped with a long neck, measuring 0.87—1.2 in length and 0.17—0.2 in maximum breadth across the bulb. The latter contains a cone-shaped pars prostatica of  $0.35 \times 0.09$  size which is surrounded by well developed prostate gland cells. The genital pore lies in the median line close behind the oral sucker.

The irregularly lobed ovary, 0.26—0.35 in size, is situated in the intercaecal space posterior to the mehlis gland and in level with the middle thirds of the testes. From the anterior margin of the ovary arises a short and wide oviduct which enters the mehlis gland after giving off a short Laurer's canal. The mehlis gland, 0.23—0.26 in length and 0.17—0.26 in maximum breadth, is a somewhat triangular compact structure situated just in front of the ovary. The receptaculum seminis is absent.

The vitellaria are composed of small irregular follicles of  $0.09—0.12 \times 0.05—0.08$  size which are arranged in a linear series, except at a few places, laterally outside the intestinal caeca. They begin from just behind the middle of the body and terminate a little beyond the anterior ends of the testes, extending over a length of 1.2—1.5. The transverse vitelline ducts arise from the posterior ends of the vitellaria and unite in the region of the mehlis gland to form an oval vitelline reservoir which lies to the left side in contact with the latter.

The first one or two coils of the uterus are filled with sperms forming the receptaculum seminis uterinum. The uterus, as in other members of the genus, is arranged in transverse coils in a characteristic manner in the intercaecal space between the gonads and the middle of the vesicula seminalis. Terminally it passes into a straight muscular metraterm of the same length as the cirrus sac. Eggs are small, thin-shelled, light brown in colour and are provided with long polar filament at each pole, measuring (excluding the filament)  $0.017—0.02 \times 0.008—0.01$  in size.

*C. indicus* N. Sp. differs from all the known species of the genus in many features. In its relationship it stands nearest to *C. orientalis* which it resembles in the arrangement of ventral glands, size of sucker and oesophagus, position and shape of gonads and number of uterine coils. It differs, however, from the latter in shape and size of body, absence of ventral papillae, presence of body spines, size of gonads, length of cirrus sac, position of vitellaria and size of eggs. *C. indicus* can be distinguished from *C. gallinulae* by the position of testes, large size of vesicula seminalis, lobed character of ovary and size of eggs, from *C. filamentis* by the shape and size of body, size of gonads, character of

ovary and the caudad extent of vitellaria, from *C. charadrii* by the shape and size of body, size and shape of gonads and size of vesicula seminalis; from *C. verrucosa* by the diameter of sucker, size of vesicula seminalis and character of ovary. *C. indicus* differs markedly from all the known species of the genus in the position of the genital pore which lies far forward just behind the oral sucker.

This work was carried on under Dr H R Mehra to whom my respectful gratitude is due for his kind help and suggestions. I am also grateful to Dr D R Bhattacharya for laboratory facilities and to the Trustees of the Lady Tata Memorial Trust, Bombay, for the grant of a research scholarship in Helminthology.

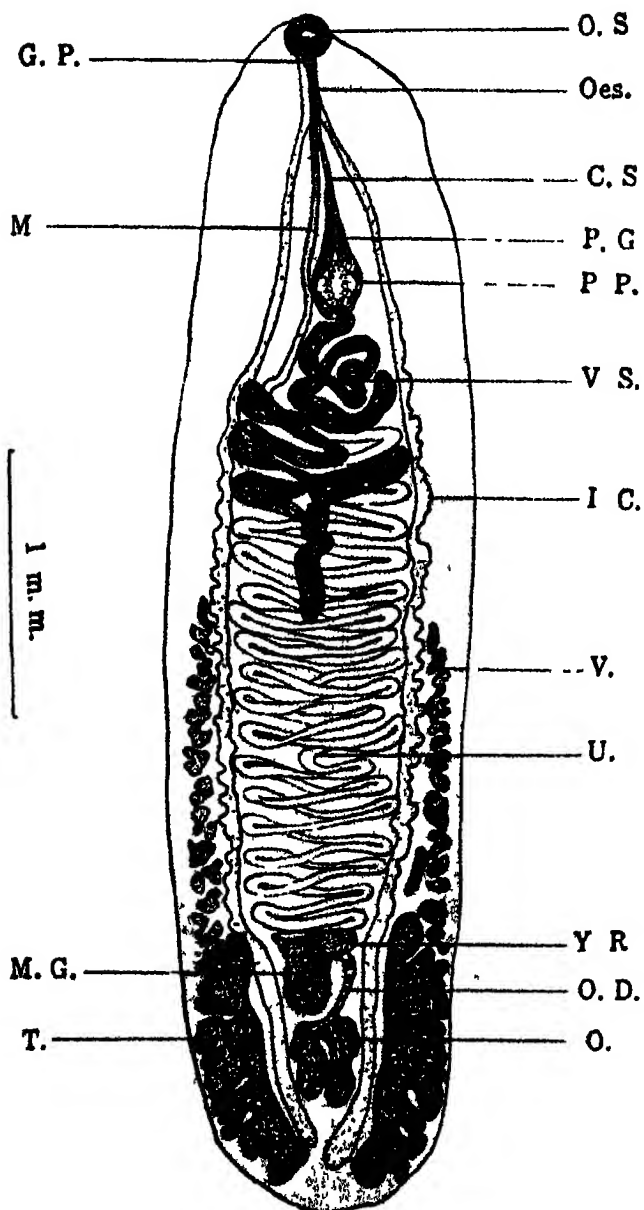
### Plate 1 Ventral View of *Catatropis indicus* N. Sp.

#### LETTERING

CS	Cirrus Sac	O.S.	Oral Sucker
GP	Genital Pore	PG	Prostate Glands
I.C	Intestinal Caecum	PP.	Pars Prostatica
M	Metraterm.	T	Testis
MG	Mehl's Gland	U	Uterus
O	Ovary	V	Vitellaria
Oes	Oesophagus.	YR	Yolk Reservoir.
O.D.	Oviduct.		

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## A STUDY OF SOME ORGANIC REACTIONS AT LOW TEMPERATURES

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Organic chemistry since its inception has always been regarded as branch of science in which fairly high temperature has always played an important part in most of the reactions. We find that most of the processes employed therein, *e.g.*, distillation, fractionation, crystallisation, dry distillation, sublimation, digestion, extraction, etc., invariably require temperatures which are much above the ordinary. And so also do most of the reactions. Thus we find that Claisen's and Knoevenagel's reactions require temperatures ranging from 50°-60° to nearly 150°. Perkin's reaction requires heating at the boiling point of at least that of acetic anhydride (128°) for several hours in order to complete the reaction. In Friedel-Craft's reaction the constituents are heated at least to the boiling point of the diluent, *i.e.*, carbondisulphide (46°) for several hours until the reaction is complete. Fittig's reaction often requires temperatures which nearly correspond to the boiling point of the halogenated benzene derivative (132° and upwards). Skraup's reaction requires temperature above 200° and Doebner-Müller's reaction requires prolonged heating at the boiling point of concentrated hydrochloric acid (110°-120°). Michael's reaction requires heating at least at the boiling point of the diluent (ether—35°, benzene—80° and amyl ether—148°) for several hours. Reformatski's reaction is also identical with Grignard and Michael's reactions in this respect. Thorpe's reaction requires heating with 75-80% sulphuric acid (210°-230°). Reimer-Tiemann's reaction requires a temperature from 60° to 80° for several hours. Kolbe's reaction has an optimum temperature near about 200°, and Beckmann's transformation and Walden's inversion require temperatures near about the boiling point of ether or benzene. Hydrolysis of cane sugar is generally effected at 60° and hydrolysis of an ester with caustic potash at 70°-80°.

In short, most of the organic reactions, *e.g.*, hydrolysis, dehydration, condensation, etc., require temperatures above the ordinary. In very rare

instances we come across reactions which have been carried on at the melting point of ice. But we hardly find any example in which a reaction has been performed below  $0^{\circ}$ , i.e., at a temperature of say  $-6^{\circ}$  to  $-10^{\circ}$ . On account of the great paucity of data with regard to this point of view, the present investigation was undertaken in order to find out interesting types and examples of organic reactions which would go on well even at such low temperatures.

It has now been found in general that low temperature reactions studied in course of the present investigation are really somewhat slow as compared with the same carried on at higher temperatures. Of course this can be easily expected as heat is a great promoter of reactions. But there are some reactions which simply do not get on at low temperatures, e.g., condensations of malonic acid with veratric aldehyde, isovaleraldehyde, isobutyraldehyde *p*-oxybenzaldehyde etc. In some cases it has been found that low temperature reactions are not quite analogous to the reactions carried on at higher temperatures, e.g., *o*-nitrobenzaldehyde condenses with acetone at  $40^{\circ}$  in presence of dilute alkali with formation of the unsaturated ketone—*o*-nitrobenzylideneacetone, but the same reaction carried on at temperature of  $-6^{\circ}$  gave only indigo. Cane sugar which undergoes quantitative hydrolysis in 20 minutes at  $60^{\circ}$  by 5% hydrochloric acid, was altogether unaffected by the same reagent at  $-6^{\circ}$  in 20 hours. In the hydrolysis of esters of various description it was found that the velocity of hydrolysis was exceedingly reduced, e.g., benzyl-cinnamate which undergoes complete hydrolysis at  $80^{\circ}$  by caustic potash (10%) in 12 minutes, was hydrolysed to the extent of only 98% in course of 12 days. Benzoin condensation which gave an yield of 90% after heating only for an hour at high temperature, gave only an yield of 35.5% at  $-6^{\circ}$  after 72 hours. Hydroquinone got oxidised to quinhydrone by ferric alum at  $-6^{\circ}$  to the extent of 73.3% after 24 hours, and quinone was reduced to hydroquinone by sulphurous acid to the extent of 58.3%. In some cases low temperatures have been found to be slightly more efficacious in conducting reactions than higher temperatures. Thus the formation of hydrobenzamide is 97.2% at  $-6^{\circ}$  to  $-10^{\circ}$ , whereas the same reaction at  $30^{\circ}$  gave an yield of not more than 85%. The formation of phenoquinone is 61% at  $-6^{\circ}$  and 52% at  $80^{\circ}$ , of oxamide is 56.4% at  $-6^{\circ}$  and 47% at  $60^{\circ}$ .

The great difference between condensation products at low temperature and high temperature is that the crystalline structure of products formed in the former case is far more well marked and definite than in the latter. The amount of by-products formed is also much smaller at lower temperature, and in most of the cases no by-products are formed at all,

the compound obtained being exceedingly pure. The second difference lies in the great varieties of exhibitions of colour which low temperature reactions produce, before the final product is formed. The explanation for colour variations during the course of condensations can be found either in Vorlander's<sup>1</sup> hypothesis of formation of unstable intermediates or in Dewar's<sup>2</sup> hypothesis of different degrees of hydration of condensation products.

Lastly, the marked gradations in the yield with respect to the amount of condensing agent added is of great interest. In some cases it has also been possible to note that further addition of the condensing agent has no effect in the increase of the yield, after a certain percentage of yield is obtained.

The experimental portion of the investigation has been classified under the following four heads:

1. Condensation
2. Oxidations, reductions, preparations
3. Hydrolysis
4. Transformations

## EXPERIMENTAL

The low temperature thermostat used in course of these experiments was a Frigidare refrigerator specially equipped and adjusted so as to give a temperature of  $-20^{\circ}$  in the freezing coils and between  $-10^{\circ}$  to  $-6^{\circ}$  in the chamber. It was here that all the reactions described in this paper were carried out.

*Condensation of cyclo-pentanone and ethyl-cyanacetate in presence of piperidine*—8.9 c.c. of an equimolecular mixture of cyclopentanone and ethyl-cyanacetate were taken in each one of 13 different flasks and they were kept in the Frigidare until they attained the inside temperature. Different quantities of well cooled piperidine were then added to the flasks and they were allowed to stand in the refrigerator for 24 hours. After that period dilute hydrochloric acid was added to each of the flasks in order to destroy the condensing agent and arrest the reaction. The reaction product from each of the flasks was submitted to steam distillation so as to remove the unreacted constituents. The residual condensation products were carefully recrystallised under identical conditions and the



yield noted in each case. The results are summarised in the table given below

No of flask	Amount of piperidine added	Weight of condensation product	% yield
1	0.02 c c	2.6790 g	14.00
2	0.04 c c	4.8258 g	37.80
3	0.06 c c	5.4300 g	44.50
4	0.08 c c	6.1630 g	60.83
5	0.10 c c	6.5701 g	65.34
6	0.12 c c	6.9654 g	69.70
7	0.14 c c	7.1030 g	71.24
8	0.16 c c	7.2150 g	72.40
9	0.18 c c	7.2908 g	73.30
10	0.20 c c	7.3990 g	74.40
11	0.22 c c	7.4980 g	76.22
12	0.24 c c	7.5021 g	76.32
13	0.26 c c	7.5500 g	76.40

Thus it is apparent from the above table that the yield of the condensation product increases with the increase of the amount of the condensing agent added until it comes to 0.22 c c. After that further addition of piperidine has no effect in the increase of the yield of cyclopentylidene-ethyl-cyanacetate. The condensation product crystallises in colourless needles from alcohol melting at 52°.

*Coumarin-carboxylic ester from salicylaldehyde and malonic ester in presence of piperidine*—This condensation was also effected in a manner similar to the above. The best yield was obtained when the proportion of piperidine to that of the other two constituents mixed together was in the ratio of 1 : 30, i.e., 3.3%. The substance crystallises from acetone in colourless needles, melting at 52°. The optimum yield was 62.6%.

For the sake of abbreviation, the rest of the condensation work is summarised in tabular form. (The Duration of cooling was 24 hours in each case).

Condensation product	Constituents	Condensing agent	Optimum % of condensing agent	Optimum yield %	M.P. of condensation product
Benzylideneacetophenone	benzaldehyde & acetophenone	10% NaOH	6.8	70.4	57
Benzylidene-ethyl-cyanacetate	benzaldehyde & ethyl-cyanacetate	6% NaOET	15.4	81.3	51°
Furylideneacetone	furfural & acetone	6% NaOET	19.0	40.2	91°

Condensation product	Constituents	Condensing agent	Optimum % of condensing agent	Optimum yield %	M P of condensation product
Benzylidene acetone	benzaldehyde & acetone	ditto	17.8	51.2	42°
Piperonal acetone	piperonal & acetone	25% NaOH	2.9	24.8	106°
Indigo	o-nitrobenzaldehyde and acetone	ditto	2.4	38.4	.
Cinnamylidene acetone	cinnamaldehyde & acetone	15% NaOH	16.3	36.3	67°
Benzoin	benzaldehyde & KCN	10% KCN	18.8	24.3	134°
Furylidene ethylcyanacetate	furfural & ethyl cyanacetate	10% NaOH	13.7	70.8	93°
Benzylidene aniline	benzaldehyde & aniline	6% NaOET	16.0	83.7	54°

#### OXIDATION

*Quinhydrone from quinol.*—2.5 grams of quinol dissolved in 25 c.c. of water and 3.62 grams of ferric alum dissolved in 10 c.c. of water were placed inside the refrigerator until the temperature was about  $-6^{\circ}$ . They were then mixed together and allowed to stand at that temperature for 24 hours. The quinhydrone was then filtered off, washed and dried. M. P.  $171^{\circ}$ . Yield—17.3%.

#### HYDROLYSING CONDENSATION

*Hydrobenzamide from benzaldehyde and ammonia.*—5 c.c. of freshly distilled benzaldehyde and 25 c.c. of strong ammonia were individually cooled and then mixed together and allowed to stand inside the refrigerator. After 24 hours the precipitated solid was filtered off, washed, dried and weighed. M. P.  $105^{\circ}$ . Yield—97.26%.

#### POLYNUCLEAR CONDENSATION

*Phenoquinones from phenol and quinone.*—4.7 grams of pure phenol dissolved in 10 c.c. of petroleum ether and 2.7 grams of quinone also dissolved in 10 c.c. of petroleum ether were individually cooled and then mixed together. After 24 hours the precipitated crystalline phenoquinone was filtered off, washed with little petroleum ether, dried and weighed. M. P.  $71.5^{\circ}$ . Yield—61.0%.

#### REDUCTION

*Quinol from quinone.*—2 grams of quinone were treated with an ice-cold saturated aqueous solution of sulphur dioxide (30 c.c.) and the

mixture kept inside the refrigerator After 24 hours the product was filtered from the unreacted quinone and from the filtrate the quinol was extracted with ether. After recrystallisation with the addition of a little animal charcoal the substance melted at  $169^{\circ}$  Yield—58.32%

*Phenylhydrazine from diazobenzene chloride*—10 grams of aniline were diazotised as usual in dilute hydrochloric acid solution keeping the temperature below  $-5^{\circ}$  60 grams of stannous chloride dissolved in 30 c.c. of concentrated hydrochloric acid were also brought to the same temperature and then the two solutions were mixed together and the mixture allowed to stand inside the refrigerator After 24 hours the crystalline precipitate was filtered off, washed with icecold concentrated hydrochloric acid and dried on a porous plate in the lime desiccator The phenylhydrazine hydrochloride thus obtained was quite pure and was weighed Yield—74.23%

*Hydrolysis of cane sugar*.—5 grams of cane sugar dissolved in 100 c.c. of water and cooled to  $-6^{\circ}$  were treated with 5 c.c. of concentrated hydrochloric acid (35.4%) also kept at the same temperature, and the mixed solutions allowed to stand inside the refrigerator The amount of hydrolysis was ascertained from time to time by withdrawing a measured sample and after neutralisation, titrating it with standard Fehling's solution The results are given below

Time in hours	Percentage of hydrolysis
24	2.65
48	23.46
72	35.62
96	39.84
120	58.83
144	66.81
216	76.93
288	80.00
384	90.90
480	96.86
720	99.86

From the above it can be said that cane sugar solution with 5% strong hydrochloric acid requires 30 days for complete hydrolysis at  $-6^{\circ}$

*Hydrolysis of an ester, e.g., benzyl-cinnamate*.—A 5% solution of benzyl-cinnamate in alcohol was treated with an equal volume of N/6.2 alcoholic caustic potash at  $-6^{\circ}$  and the mixture kept in the refrigerator. From time to time a sample of the liquid was withdrawn and the amount of

hydrolysis produced in it was measured by titrating it against standard acid. The results are given below

Time in hours	Percentage of hydrolysis
24	16
48	36
72	76
120	90
172	981
240	998
afterwards	no further change

*Benzidine transformation*—2.5 grams of hydrazobenzene dissolved in 40 c.c. of 50% alcohol and 1.5 grams of stannous chloride dissolved in 3 c.c. of concentrated hydrochloric acid were individually cooled and then mixed together and kept inside the refrigerator. After 24 hours the precipitated crystalline solid was filtered off, washed with concentrated hydrochloric acid, and dried on a porous plate in the lime desiccator. The weight of the benzidine hydrochloride thus obtained was 2.40 grams which corresponds to a yield of 81.4%.

*Beckmann's transformation*—2.5 grams of acetophenone oxime dissolved in 30 c.c. of anhydrous ether and 3.8 grams of phosphorus pentachloride were individually cooled and mixed together and the mixture allowed to stand in the refrigerator. After 48 hours the phosphorus pentachloride was destroyed by the addition of 30 gms. of ice and the ether removed by distillation. The insoluble product was filtered off, washed with dilute sodium hydroxide in order to remove any unchanged acetophenone oxime, and water, dried and weighed. The substance which was identified to be acetanilide weighed 0.336 gm., and melted at 115°. The yield correspond to 13.4% of the theoretical.

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# CHEMICAL EXAMINATION OF THE ROOTS OF *CITRULLUS COLOCYNTHIS* SCHRADER

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Received November 24 1934

*Citrullus colocynthis*, (N O Cucurbitaceae) called Colocynth or bitter apple in English, *Indrayan* in Hindi and Bengali, *Hanzul* in Persian, and *Indravaran* or *Vishala* in Sanskrit, is a plant used in medicine for a very long time. It is grown wild in waste tracts of North-West, Central and South Indies, and Beluchistan. The fruit is globular of the size of an orange when ripe. The root is fibrous, tough stinging of an yellowish white colour. All parts of the plant are very bitter.

The fruit of this plant has been the subject of many investigations. Walz<sup>1</sup> claimed to have isolated a glucoside called colocynthin in 1858, which was evidently an amorphous mass. Later on in 1883 Hencke<sup>2</sup> examined the fruits and failed to obtain the glucoside isolated by Walz. Johannson<sup>3</sup>, two years later, obtained the glucoside colocynthin and showed that this on hydrolysis yields the aglucone colocynthein along with elaterin and bryonin. Naylor and Chappel<sup>4</sup>, working on the Indian variety, succeeded in confirming the results of Walz<sup>1</sup> by a modification of the method adopted by Hencke<sup>2</sup>, and isolated the so-called glucoside in a crystalline form. They also stated that their product on hydrolysis yielded amongst other substances, colocynthein and elaterin, thus confirming the results of Johannson<sup>3</sup>. More recently Power and Moore<sup>5</sup> thoroughly examined the pulp of the fruits of Colocynth. In the course of their elaborate investigation they isolated the following substances: a di-hydroxy alcohol citrullol,  $C_{22}H_{46}O_2(OH)_2$ , m.p. 285-290°, an amorphous alkaloid,  $\alpha$ -elaterin, m.p. 230°, hentriacontane,  $C_{31}H_{64}$ , m.p. 68°, and a phytosterol,  $C_{27}H_{46}O$ , m.p. 160-162°.

In spite of so much literature on the chemical examination of the fruits of Colocynth, the roots of the plant remain untouched. The only reference found is a note by Dymock<sup>6</sup>, in which he mentions that he "examined the roots dried at 50°C and reduced to powder; the powder contains a large amount of starch and woody fibre. Ether extracted only

0.14% of a bitter oily matter. Dilute alcohol extracted 12.62% of a soft yellow non-crystalline mass dried at 100°. By the action of cold water on the extract 0.88% of insoluble soft yellow residue was left, which was not bitter and had acidic reactions—a fatty acid. In view of the fact that the roots are also put to a great medicinal use in India and elsewhere, it was deemed proper by the present authors to put it to a thorough chemical examination.

As regards the medicinal properties of the roots, "Sanskrit writers describe it as a useful cathartic in jaundice, ascites, enlargement of the abdominal viscera, urinary diseases and rheumatism, etc. Mohammedan writers consider the plant to be a very drastic purgative removing phlegm from all parts of the system and direct the fruit, leaves and roots to be used. A paste of the root is applied to the enlarged abdomen of children" (Dymock<sup>6</sup>).

The present investigation has shown that the roots contain like the fruits a considerable quantity of  $\alpha$ -elaterin (0.2%), an amorphous saponin (1.2%), hentriacontane, inorganic materials and reducing sugars. The  $\alpha$ -elaterin is not present in so huge a quantity as that reported from the pulp of the fruit which was about one per cent. The preliminary examination showed the presence of alkaloids in the root, but all attempts to isolate them failed.

The constitution of  $\alpha$ -elaterin has not yet been definitely established. F. Von Hemmelmayer<sup>7</sup> prepared from it a di-acetyl derivative which was not crystalline. We have, however, been successful in obtaining the diacetyl derivative in a crystalline form by heating together,  $\alpha$ -elaterin and acetic anhydride with fused sodium acetate for 18 hours over a sand bath and crystallising the product from acetic acid.

### EXPERIMENTAL

The roots were obtained from the local market and were finely crushed in an iron mortar. When burnt completely in a porcelain dish there was left 10.01% of a dirty white inorganic ash. The ash contained 12% of water soluble and 88% of water insoluble inorganic matter. The following elements and radicals were detected in the ash: chloride, sulphate, carbonate, potassium, magnesium, aluminium (traces), iron, calcium and silica.

In order to ascertain the general characteristics of the soluble portion of the roots, samples of finely powdered material were exhaustively extracted in a Soxhlet extraction apparatus using various solvents.

The following statement contains the amount of extract dried at 100° obtained

1 *Petroleum Ether Extract*.—101% The extract was oily and contained a lot of chlorophyll and waxy matters

2 *Benzene Extract* —3.30% A green extract was obtained having properties similar to the petroleum extract obtained above

3 *Acetone Extract* 8.78% Brownish red extract, giving characteristic smell Gave reactions for carbohydrates, glucosides, alkaloids and had properties similar to the alcoholic extract

4 *Alcoholic Extract* —12.9% Brownish yellow extract giving the characteristic smell of the plant It contained some crystalline matter suspended in it It gave a precipitate with lead acetate, and silver nitrate, reduced Fehling's solution Gave a green colouration with ferric chloride, a precipitate with phosphotungstic acid and Mayer's reagent.

5. *Aqueous Extract*.—4.1% A brown coloured extract It reduced Fehling's solution easily, showing the presence of large amount of reducing sugars, also gave reactions for saponins Formed a violet colouration with  $\alpha$ -naphthel in chloroform solution and concentrated sulphuric acid A precipitate was formed with lead acetate

A preliminary examination for alkaloids was made with 200 grams of the powdered stuff The alcoholic extract was diluted with water and treated with a little hydrochloric acid It was then tested with various alkaloid reagents whereby the following precipitates or colouration were observed, showing definitely the presence of an alkaloidal body in the roots

<i>Alkaloidal reagents</i>	<i>Remarks.</i>
Fröhdes reagent.	A brownish colouration
KI + I <sub>2</sub>	A reddish brown precipitate
Mendelin's reagent.	A brownish colour with some precipitate
Phosphotungstic acid	A green precipitate.
Phospho-molybdic acid	A white precipitate
Mayer's reagent	A dirty white precipitate
Con H <sub>2</sub> SO <sub>4</sub> + K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	No change
Con H <sub>2</sub> SO <sub>4</sub> + HNO <sub>3</sub>	No change
Dragendroff's reagent	A deep brown precipitate.
Sodium bicarbonate	No change
Picric acid	A yellow precipitate.

For a complete analysis 2 kilograms of the powdered roots were exhaustively extracted with boiling alcohol in a big extraction flask of five litre capacity in two lots of 1 kilogram each. Seven extractions were necessary to remove all the soluble portions. The combined alcoholic extract on partial removal of the solvent yielded a crystalline stuff which was filtered, washed and dried when it melted at  $227^{\circ}\text{C}$ . It amounted to 0.6 grams. It was recrystallised from boiling alcohol when it was obtained as a white crystalline powder melting sharp at  $229\text{--}230^{\circ}\text{C}$ . It was later on identified to be  $\alpha$ -elaterin.

*Isolation of a hydrocarbon*—The alcoholic extract on the removal of the crystalline stuff, was evaporated to dryness on a water-bath, when it was obtained as a dark brown highly hygroscopic mass. It was then refluxed with petroleum ether, in order to remove chlorophyll and other oily constituents. The petroleum ether extract, which was light green in colour, slowly deposited a small amount of a white crystalline sediment. It was then filtered and the dirty white sediment recrystallised from hot petroleum ether whereby it was obtained in white flakes melting at  $66\text{--}67^{\circ}\text{C}$ . It was most probably the hydrocarbon hentriacontane  $\text{C}_{31}\text{H}_{64}$  isolated by Power and Moore<sup>b</sup> from the fruits. However, the quantity at our disposal was too small for any further investigation.

*Isolation of  $\alpha$ -elaterin*.—The resinous mass left after treating the alcoholic extract with petroleum ether was extracted with ethyl acetate till ethyl acetate ceased to dissolve anything. The combined ethyl acetate extract on concentration deposited a white powder, which was filtered, washed and dried in vacuum. It was recrystallised from hot boiling alcohol whereby a small amount (3 grams) of micro-crystalline powder was obtained melting sharp at  $229\text{--}230^{\circ}\text{C}$ . It was very little soluble in alcohol, acetone, and ethyl acetate and practically insoluble in petroleum ether, benzene and water. It gave a yellow colouration with concentrated sulphuric acid, which on heating deposited some amorphous mass. It dissolved on boiling in caustic potash with a deep red colouration. It reduced Tollen's reagent readily and gave a red colouration with alkaline potassium nitroprusside. From all its properties, colour reactions and elementary analysis, the stuff was shown to be  $\alpha$ -elaterin (Found. C, 69.0; H, 7.5,  $\text{C}_{28}\text{H}_{48}\text{O}_7$  requires C, 69.1; H, 7.8%).

This substance was laevo-rotatory and gave  $[\alpha]_D^{25} = -62.3^{\circ}$  in chloroform solution in a 1 dm. tube. In order to confirm the identity of this substance with  $\alpha$ -elaterin, the acetyl derivative was prepared in the usual way.

*Is-acetyl  $\alpha$ -elaterin*—0.5 grams of the  $\alpha$ -elaterin was heated in a round-bottomed flask with excess of acetic anhydride and fused sodium



acetate The mixture on cooling was poured in excess of water, whereby a brown amorphous product was obtained It was crystallised from acetic acid when rhombic plates were obtained melting at  $122-123^{\circ}$  (c f F Von Hemmelmayr,<sup>7</sup> [Found C, 67.10, H, 7.80,  $C_{12}H_{12}O_6$  requires C, 67.43, H, 7.4%]

The crystalline stuff obtained from the alcoholic extract in the beginning which melted at  $229^{\circ}\text{C}$  was also suspected to be  $\alpha$ -elaterin In order to establish this a little of the former was mixed with a little of the latter and the melting point observed was not depressed The two products were therefore mixed

The ethyl acetate extract, from which  $\alpha$ -elaterin was separated, was evaporated to dryness, when a resinous material was obtained This was dissolved in hot acetone At this stage a white sediment (0.2 gram) remained undissolved which was identified as  $\alpha$ -elaterin Nothing definite could be separated from this acetone extract

*Isolation of Saponin* - The dried alcoholic extract which remained undissolved in ethyl acetate as described above, was dissolved in water with constant stirring and treated with a solution of lead acetate when no precipitate was formed On treating it with basic lead acetate, however, a flocculant yellow precipitate was obtained which was filtered and washed thoroughly This lead salt was suspended in water and decomposed as usual with sulphuretted hydrogen The precipitated lead sulphide was filtered and washed The filtrate obtained after the removal of the lead sulphide was concentrated under a very high vacuum, when a dark brown stuff was obtained on complete removal of water It was dried in vacuum over calcium chloride This resinous mass consisted mostly of saponins since on shaking it with water a large amount of frothing took place A red colouration was obtained in cold on the addition of concentrated sulphuric acid A Turnbulls blue colouration was developed on the addition of potassium ferricyanide containing a little ferric chloride All these reactions clearly showed the presence of a large amount of saponins An attempt was made to isolate it in a state of purity by precipitation with an alcoholic solution of cholesterol as cholesterolide but could not be met with success

The filtrate obtained after the separation of the basic lead salt was treated with hydrogen sulphide to remove the excess of lead and filtered It reduced Fehling's solution easily showing the presence of a large amount of reducing sugars

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## SUMMARY

From the roots of *Citrullus colocynthis*, a hydrocarbon, hentriacontane  $C_{31}H_{64}$ ,  $\alpha$ -elaterin  $C_{28}H_{48}O_7$  and amorphous saponin have been isolated.

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ON THE DETERMINATION OF ABSORPTION COEFFICIENTS  
OF SOUND FOR DIFFERENT MATERIALS

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**Abstract**

Sound absorption coefficients have been obtained by the Stationary Wave Method of E. T. Paris. The source of Sound was a valve-maintained tuning fork oscillator, coupled with a single stage valve amplifier. The output of the source was carefully kept constant, and any change in it was at once detected by a Weston Galvanometer which was fed by direct current from a Copper oxide metal rectifier placed in series with the loud speaker. The "battery type" of bridge with a compensating microphone was used in finding the resistance changes. The detecting instrument in this bridge was a moving coil dead beat mirror galvanometer. The resistance changes at minima were observed in terms of the deflections of the spot of light from the balance point, and a sensitivity much greater than those of previous workers, who used a microammeter, was obtained. The difficulty of determining low absorption coefficients with accuracy has therefore been overcome.

Absorption Coefficients at 512 frequency for some commercial absorbing materials have been obtained. Incidentally some light has been thrown on the type of joints for acoustical purposes. The absorption coefficient of embossed metal plate (used in ceilings) painted with Lady Brand light blue paint has been determined, and information is gained as to why halls with such ceiling have generally good acoustical properties.

### Introduction

The work described in this paper is an extension of the work already started in our Laboratory about a year ago,<sup>1</sup> with the object of testing the acoustic properties of different materials at normal incidence, and to study the conditions which effect changes in these properties. In the preliminary report of their investigations they had no control over certain factors, *viz.*, stability of frequency and intensity etc, which greatly affect the final value of the Absorption Coefficient of materials. These factors of uncertainty and consequent errors have been removed and controlled. In this present work the stationary wave method<sup>2</sup> of Paris has been followed. The following is a brief sketch of the theory.

*Theory*—If a source of sound of constant frequency and intensity is placed before one end of a long cylindrical pipe, the other end of which is closed by a reflector, sound waves travel down the pipe and are reflected from the material. If the latter is a perfect reflector, such as a thick polished metal plate, there is practically no loss of energy and the amplitudes of the incident and reflected waves are the same, and stationary waves are formed in the pipe. If, however, the material absorbs part of the incident energy, the two amplitudes differ from each other, the amplitude of the reflected wave being evidently less than that of the incident wave. If it is assumed that the incident and reflected waves are plane waves, a condition which can be easily secured by adjusting the position of the source of sound before the open end of the pipe, the expression for the absorption coefficient can be obtained as was done by Paris.<sup>3</sup>

Let the axis of the pipe be parallel to the x-axis, and let the plane of the specimen be identical with the plane  $x=0$

Further, if the waves are supposed to be travelling in the positive direction of the x-axis, the potentials of the incident and reflected waves can be written down as

$$\varphi = A \cos k (\beta t + x) \quad (1)$$

$$\varphi' = B \cos k (\beta t + x + \epsilon) \quad \dots \quad (2)$$

Equation (2) takes into account the loss of energy in reflexion. The resultant potential in the pipe is given by

$$\Phi = A \cos k (\beta t + x) + B \cos k (\beta t + x + \epsilon) \quad \dots \quad (3)$$

Putting  $t' = t + \frac{\epsilon}{\beta}$  and  $x' = x + \frac{1}{2}\epsilon$  we get

$$\begin{aligned} \Phi &= A \cos k (\beta t' - x') + B \cos k (\beta t' + x') \\ &= (A + B) \cos k x' \cos k \beta t' \\ &\quad + (A - B) \sin k x' \sin k \beta t' \quad \dots \quad (4) \end{aligned}$$

We see from equation (4), that the motion in the pipe can be regarded as being the resultant of two superimposed stationary waves, one having an amplitude  $(A+B)$ , and the other  $(A-B)$ , the nodes and loops of the one being a quarter of a wavelength ahead of the other. We, therefore, find a number of positions of minimum and maximum pressure variations in the pipe, the latter being proportional to  $(A-B)$  and  $(A+B)$  respectively. The distance between a maxima and a minima is  $\lambda/4$ .

Now the flux of energy in the incident and reflected waves is proportional to  $A^2$  and  $B^2$  respectively; and by definition the coefficient of absorption ( $\alpha$ ) is given by

$$\alpha = \frac{A^2 - B^2}{A^2} \quad (5)$$

Let the observed ratio of the maximum to the minimum amplitude be  $\frac{a}{b}$ .

We have then

$$\begin{aligned} \frac{a}{b} &= \frac{A+B}{A-B} \\ \therefore \alpha &= \frac{A^2 - B^2}{A^2} = \frac{4ab}{(a+b)^2} \\ &= \frac{4}{2 + \frac{a}{b} + \frac{b}{a}} \quad \dots \quad (6) \end{aligned}$$

This is a very simple and elegant expression, which was first obtained by Hawley Taylor, and the whole problem of determining the absorption coefficients resolves into measuring the quantity  $\frac{a}{b}$  as accurately as possible.

*Description of the apparatus.*—The apparatus used is essentially similar in construction and principle to the one used by Paris (*loc cit*). It was, however, found necessary to make some modifications in design and working in order to make it conform to the theoretical assumptions, and the essential conditions of working with the hot wire microphone as closely as possible.

*Experimental Pipe and the method of mounting the specimen.*—The experimental pipe consists of a long cylindrical earthenware pipe about 2 metres in length, and 12" in internal diameter. As a single pipe of this length could not be obtained, three similar glazed drain pipes were cemented together with their axes, in a straight line. These pipes were supported on solid wooden stands which were padded to absorb any ground vibrations. One end of the pipe projects into a big wooden box

having a door which can be opened and closed easily. The crevices in the box were closed by cardboard so that the movements of the experimenter in the room did not affect the microphone inside the pipe. A moving coil loud speaker was placed inside this box, and its connecting wires were passed through narrow holes bored through the walls of the box.

The material under investigation is mounted as follows:—

A thick wooden disc of 15" diameter and 1" thick, having a handle on one side was first obtained. A brass plate,  $\frac{1}{8}$ " thick and 15" in diameter having holes near its edges, is then tightly screwed to the wooden disc. The specimen cut to the required shape and size is placed over this metal plate. Four circular pieces of wood having the same curvature as the plate, were placed over the specimen, and by means of long screws the latter was tightly fixed to the metal and wooden discs. A rubber washer made from an old bicycle tube was put round this whole arrangement, which was then inserted in the open end of the pipe remote from the loud speaker end. The space between the disc and the pipe was tightly packed by cotton waste in order to make it as perfectly air-tight as possible.

*The measuring instrument of sound.*—Hot wire microphone

The hot wire microphones used were similar in principle and design to the "selective microphone" described by Tucker and Paris<sup>4</sup>. A hollow brass cylinder of about 3 cm in diameter was put on a concentric cylinder so that one could slide over the other. The neck of the resonator was 0.2 cm in length, and 0.8 cm in internal diameter. The grids of these hot wire microphones were obtained from H W Sullivan, Ltd, London, and could carry maximum currents of 42 and 44 milliampères. They were mounted in the necks of the Helmholtz resonators which were made in the laboratory workshop. These microphones could be tuned to 512 frequency by altering the volume of the container.

One of the two microphones used was carried at one end of a long iron rod, which passed through a hole in the sound chamber. An idea of the setting of the apparatus can be gathered from the sketch given elsewhere (Fig 1).

As there is a change of resistance of the microphone when its axis is even slightly tilted (*vide* Tucker and Paris<sup>5</sup>) from its initial direction, the motion of the rod was made as smooth and easy as possible. Moreover, a thick, broad, circular wooden piece, having the same curvatures as the pipe, was transversely fixed to the rod. When the rod is moved the axis of the microphone was not altered in direction, and the unsteadiness due to tilting was greatly diminished. During the earlier parts of the work great difficulty was experienced in keeping the spot of light steady

owing to this cause, and until the motion of the rod was made quite

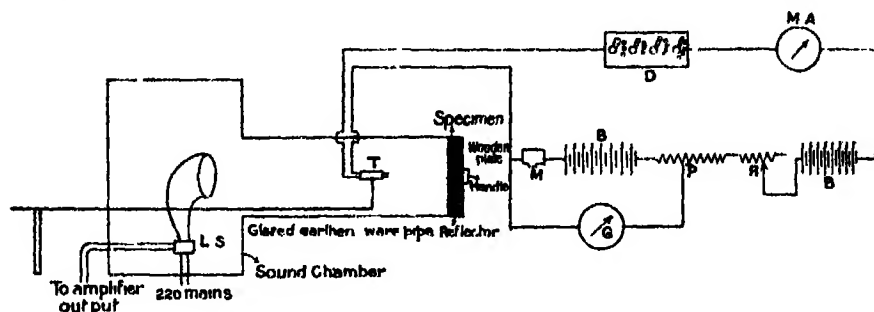


Fig 1

M A Milliammeter

G M C Dead beat mirror galvanometer

D Four dial resistance box

H Hot wire Microphone

M Compensating microphone

BB Edison cells

easy it was impossible to proceed with the work.

**Electrical Connections**—Ghosh and Mohanmad used the usual Post Office Box arrangement to measure the change of resistance of the grid when the source was switched on and off, and the microphone was placed in the required positions. Moreover, they did not use any compensating instrument. In order to get resistances of multiples of 0.1 ohm they used a Callender and Griffiths Bridge in series with the balancing arm of the P. O. Box. Their heating current of the grid was 37 m amp which they kept constant during observations. This arrangement was at first tried. A moving coil dead beat mirror galvanometer in conjunction with a lamp and scale was used as the balancing instrument. It was found, however, that when the heating current was 37 m.amp and the P.O. Box arrangement used, there was a very great unsteadiness in the spot of light, and the balance point shifted in a rather haphazard way. The difficulty could partly be ascribed to the heating of the resistances in the P O Box, and the Callender and Griffiths Bridge due to the passage of such a heavy current. But, even when thick wire laboratory made resistances were substituted for high resistances used in the P O Box, the unsteadiness of the balance point persisted. This proved a great source of trouble which took considerable time to be brought under control.

The behaviour of the microphone was then studied with increasing and decreasing heating currents, and it was eventually found that with heating currents of about 26 m amp. the balance point was pretty steady, and showed no eccentricity after the current had been passed through the circuit for about three quarters of an hour. These facts can be explained as follows: During the earlier part of the passage of current, the P. O. Box

resistances get continuously heated, and their values increase, thus shifting the balance point, and virtually exhibiting that the resistance of the grid is falling. After sometime the resistances attain their steady value and no more fluctuations should arise. After this stage the unsteadiness of the balance point, when the heating current was 37 m amp, is more difficult to explain. Probably the effect is due to the production of convection currents of air which start from one point of the grid and impinge on the other, thus producing variation in resistance of an uncertain amount. When the current is decreased, the heating is diminished, and the convection currents are also minimised.

At first no compensating microphone was used in the circuit. But even when it was used the slight unsteadiness of the balance point persisted. The heating current was of course kept constant at about 26 m. amp. Edison cells of high ampere-hour capacity (150) were used as the source of current, and a series resistance of thick wire was put to adjust it.

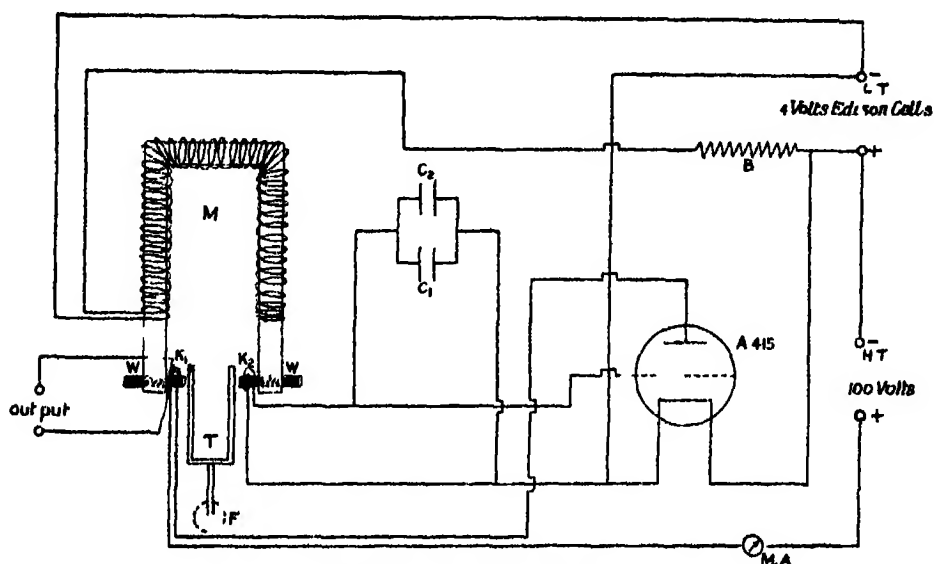
This whole arrangement was, therefore, discarded and the "battery type" of bridge was used for measuring the change in resistance. The electrical connections of the arrangement are shown in figure 1. It is similar to the arrangement used by Paris.<sup>2</sup> Greater sensitivity and steadiness of balance point were certainly obtained when this type of bridge was used. The compensating microphone, which was of the same type as the one exposed to sound, but was shielded from it in a wooden box, made the balance very steady.

The grids of the microphones carried a heating current of about 26 m amp, and had a hot resistance of about 340 ohms. When exposed to sound the fall in resistance at a maxima varied from about 13 ohms to 28 ohms, depending upon the heating current, the output of the source, and the specimen. This fall in resistance was measured by introducing resistance in the four dial resistance box, made by H. Tinsley & Co., London, which could measure from 1000—1 ohm. This bridge was initially balanced by the potentiometer arrangement P and a very low series resistance R shown in the figure. The rheostat position was of course kept fixed after the balance point had been obtained once.

*The Source of Sound.*—To obtain a source of sound which could maintain a constant output for some length of time at a fixed frequency, was a very great source of difficulty. At first a Neumann's oscillator coupled with a single stage valve amplifier, whose output was connected to a moving coil loud speaker and copper oxide rectifier, was tried. It was found, however, that the frequency of the oscillator could not be



adjusted to 512, nor could the latter be kept constant for considerable time. This arrangement was, therefore, abandoned. A valve maintained tuning fork oscillator, which was made in the laboratory, was substituted for the Neumann's oscillator. Its circuit diagram is given elsewhere (Fig 2). The output from the oscillator was amplified by a single stage

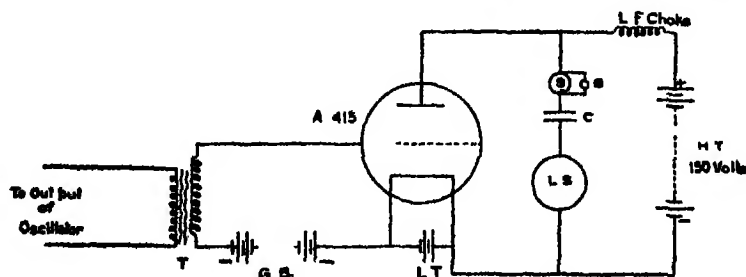


Circuit diagram of oscillator

Fig 2

- |   |   |
|---|---|
| R. A Small Wire resistance              | M Electromagnet   |
| M.A Milliammeter                        | C <sub>1</sub> & C <sub>2</sub> Condensers                    |
| W Pole pieces made of a bundle of wires | F Base where the tuning fork was fixed                        |
| T Tuning fork                           | K <sub>1</sub> , K <sub>2</sub> Coils wound over wooden reels |

valve amplifier (Fig. 3), as in the former arrangement. Across the output



Circuit diagram of amplifier

Fig. 3

- |                        |                                 |
|------------------------|---------------------------------|
| T. Input transformer   | G.B. Grid Bias battery          |
| C. Condenser           | L.S. M.C. Loud speaker          |
| G. Weston galvanometer | S. Copper oxide Metal Rectifier |

of the amplifier a capacity, a loud speaker and a copper oxide rectifier, to which a Weston D.C. galvanometer was connected in parallel, were placed. The rectifier fed direct current in the galvanometer, whose deflexions thus indicated the output of the loud speaker. This arrangement was very sensitive, and even a slight change in the output could be at once observed. A millimeter in the plate circuit of the oscillator valve showed the constancy of the oscillator output. The only factor over which I had no control for keeping the output of the source constant, was the 220 mains which was used in exciting the electromagnet of the moving coil loud speaker. However, by working at suitable times when the load on the mains was not excessive, the exciting voltage could be kept fairly constant. The stability in the construction of the oscillator, and the constancy of the voltages of the batteries used in supplying the high and low tensions to the oscillator and amplifier kept the output of the source constant.

*Method of observation.*—As has been mentioned before it was our purpose to find  $\frac{a}{b}$  as accurately as possible, and the following method was employed

The microphone was at first tuned to the note given out by the loud speaker by altering the volume of the container, and making the deflexions at a minima as large as possible

The next step was to fix up the position of the loud speaker before the open end of the pipe in order to produce stationary waves. With a certain position of the loud speaker, the deflexions at various positions of the microphone inside the pipe were noted, and a graph of the relative positions of the microphone and the deflexions plotted. The loud speaker was shifted backwards and forwards till this graph was a smooth curve of the type shown in figure 4. During both these experiments the brass plate reflector was placed at the end of the pipe opposite to the loud speaker end.

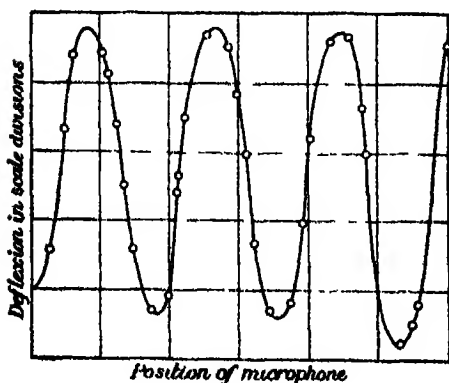


Fig 4

The deflexion obtained, when the microphone was placed at a minima after being properly tuned, was as large as 8 to 10 cms. This deflexion

corresponds to the resistance change at the minima. A deflexion of this order is much greater than that obtained by others<sup>4</sup> who have used a microammeter for guiding the change in resistance at a minima. A galvanometer of the type I have used is certainly a more sensitive instrument than the microammeter, which is, however, much less troublesome to work with. The percentage of error in determining  $a/b$  is, therefore, very much minimised. Moreover, the use of a galvanometer makes the apparatus susceptible to the measurement of very small absorption coefficients.

The specimen under test was mounted in its place as explained in the earlier pages, and the bridge was balanced by shifting the pointer P (For convenience and ease in working, a number of switches for turning the various low and high tension batteries on and off, were fixed up in the working table in front of the experimenter). The source of sound was turned on, and the microphone moved by the slider till the position of minimum deflexion near the specimen was obtained. The resistance change,  $\rho_1$ , in terms of the galvanometer deflexion was noted. The microphone was then moved, away from the specimen, and the resistance change,  $\rho_2$ , at the maxima determined. This was done by slowly introducing resistance in the dial resistance box D, and obtaining the balance point. This procedure had to be adopted as the deflexion at a maxima was so great that the spot of light was completely absent from the scale. To determine the exact position of a maxima the rod was slowly moved while the resistance introduced in D nearly corresponded to the resistance change at maxima. When the maximum deflexion on the scale was obtained in this state, the balance was obtained and the resistance change noted. A few trial experiments very much simplified further observations. Besides the use of a variable resistance of 1 megohm in series with the galvanometer was a great source of convenience in obtaining the balance point at a maxima. Let these two resistance changes be  $\rho_1$  and  $\rho_2$ , respectively.

The specimen was now removed, and the perfect reflector, (which was simply a brass plate of  $\frac{1}{4}$ " thickness) was mounted in its place. The bridge was again balanced, and the position of the node nearest the reflector was found by sliding the microphone in the pipe. In this position there should be no deflexion of the spot if the reflexion is perfect, since, however, it is never the case, a deflexion of a few millimeters always occurs, which is neglected without appreciable loss in accuracy. The microphone was then displaced, first on one side and then on the other of this minimum position till a deflexion corresponding to the resistance change  $\rho_1$  was obtained in

each case. Both these positions were noted on the horizontal cathotometer scale. Let the distance between them be denoted by  $2Y_1$ . The position of the node was also noted on a scale placed horizontally along the bar.

The microphone was then displaced, away from the specimen; but before doing so a resistance equal to  $\rho_2$  was introduced in the resistance box D, and by slowly decreasing the variable resistance in series with the galvanometer a balance point was obtained for a certain position of the microphone. This position was noted on the scale. Let the distance through which the microphone has been moved from minima to this point be called  $Y_2$ .

Now since in a stationary wave, the pressure amplitude at a point is proportional to  $\sin KY$ , where  $Y$  is the distance from the node to the point,

## OBSERVA

Material	Heating current of the grids in milli-amps.	Specimen in position			Reflecting plate in position Scale readings on a cathotometer for resistance change $\rho_1$ taken on both sides of the minima		
		Res. change $\rho_1$ at 1st minima in scale divisions	Intensity of source in scale divisions of galvanometer	Res. change $\rho_2$ at maxima in ohms.	A	B	$2Y_1$ in cms.
1. Felt 1" thick	26 (approx)	79	18	27.4			
		78	18	27.2	3 145 cms.	1 490 cms.	1 655
		78	18	27.2	3 150 "	1 480 "	1 670
		77	18	27.2	2 810 "	1 135 "	1 675
		79	18	27.2	2 895 "	1 130 "	1 675
		78	18	27.2			
2. Acoustic asbestos 1" thick obtained by courtesy of Bird & Co., Cawn- pore.	26 (approx)	21	18	28.6	2 825 cms.	2 005 cms.	0 820
		23	18	28.6	2 870 "	2 050 "	0 830
		22	18	28.6	2 890 "	2 100 "	0 790
		20	18	28.5	2 905 "	2 100 "	0 805
		20	18	28.6			
		20	18	28.7			

and  $K = \frac{2\pi}{\lambda}$ , the pressure amplitudes which produce resistance changes of  $\rho_1$  and  $\rho_2$  must be proportional to  $\sin KY_1$ , and  $\sin KY_2$  respectively. We have, therefore

$$\frac{a}{b} = \frac{\text{the pressure amplitude at maxima}}{\text{the pressure amplitude at minima}} = \frac{\sin KY_2}{\sin KY_1}$$

$$\text{and } \alpha = \frac{1}{2 + \frac{a}{b} + \frac{b}{a}} = \frac{4}{2 + \frac{\sin KY_2}{\sin KY_1} + \frac{\sin KY_1}{\sin KY_2}}$$

The value of  $K$  was found by noting the distance through which the microphone had to be shifted from one minima to another, and dividing  $\pi$  by this distance. Knowing  $Y_1$  and  $Y_2$ , the value of  $\alpha$  was calculated.

## TIONS

Mean $2Y_1$ in cms	Length of the rod moved from minima to the position where the resistance change was $\rho_2$	Mean $Y_2$ in cms	$\lambda/2$ from one minima to another in cms	Mean $\lambda/2$ in cms	$KY_1$	$KY_2$	$\alpha$ at 512 frequency	Date of observations
1.669	13.58 cms 13.48 " 13.57 " 13.52 "	13.538	33.9 cms 33.9 " 33.9 "	33.9	4°, 26'	71°, 54'	0.278	27th December, 1934.
0.8088	20.15 cms 20.45 " 20.45 " 20.15 "	20.80 cms.	33.85 cms 33.90 " 33.85 " 33.80 " 33.90 "	33.86	2°, 9'	72°, 6'	0.146	30th December, 1934.

Material	Heating current of the grids in milli-amps	Specimen in position			Reflecting plate in position. Scale readings on a cathetometer for resistance change $\rho_1$ taken on both sides of the minima.		
		Res change $\rho_1$ at let. minima in scale divisions	Intensity of source in scale divisions of galvanometer	Res change $\rho_2$ at maxima in ohms	A	B	$2Y_1$ in cm.
3. 'Troctax' $\frac{1}{8}$ " thick obtained by courtesy of Heatley Gresham, Ltd., Calcutta	23 m Amp (approx)	105	20.5	14.4			
		104	20.5	14.3	3800 cms	0.810 cms	2.990
		104	20.5	14.4	3.635 "	0.705 "	2.930
		104	20.5	14.4	3.535 "	0.665 "	2.870
		103	20.5	14.5	3.620 "	0.725 "	2.895
		104	20.5	14.4			
4. Embossed metal plate (obtained by courtesy of Winter Bros, Calcutta) painted with two coats of Lady Brand Light Blue paint	23 (approx)	18	20.5	13.5			
		19	20.5	13.5	2.790 cms	1.595 cms	1.195
		18	20.5	13.6	2.695 "	1.565 "	1.130
		18	20.5	13.5	2.735 "	1.575 "	1.160
		18	20.5	13.6	2.845 "	1.615 "	1.230
		17	20.5	13.5			
5. Felt $\frac{1}{8}$ " thick same as No 1. Re-investigated to verify the other values	25 (approx)	27	20.5	17.1	2.685 cms	1.410 cm	1.275
		26	20.5	17.1	2.740 "	1.390 "	1.350
		26	20.5	17.0	2.730 "	1.405 "	1.325
		26	20.5	17.3	2.700 "	1.405 "	1.295
		26	20.5	17.1			
		26	20.5	17.2			
6. Red cloth, known in Hindustani as "Tool". It was mounted at a distance of about one and a half cm from the reflecting plate.	25 (approx.)	10	20.5	17.7	1.585 cm	0.75 cm	0.785
		11	20.5	18.3	1.725 "	0.805 "	0.820
		10	20.5	18.0	1.645 "	0.800 "	0.845

TIONS

Mean $2Y_1$ in cms	Length of the rod moved from minima to the position where the resistance change was $\rho_2$	Mean $Y_2$ in cms	$\lambda/2$ from one minima to another in cms	Mean $\lambda/2$ in cms	$KY_1$	$KY_2$	$\alpha$ at $\lambda/2$ frequency	Date of observations
2921	241 cms 240 " 240 " 240 "	24.025 cms	34.2 cms 34.0 " 34.1 " 34.1 " 34.2 "	34.12	7°, 42'	53°, 12'	0.491	16th February, 1935
1179	25.15 25.00 25.15 25.20	25.125	34.2 34.0 34.1 34.0 34.0	34.06	3°, 7'	47°, 12'	0.257	17th February, 1935
1311	25.0 24.8 24.8 24.8	24.8	34.2 34.2 34.2 34.2	34.2	3°, 27'	49°, 30'	0.272	19th February, 1935
0850	23.3 23.0 23.4	23.23	34.2 34.1 34.2	34.16	2°, 14'	57°, 36'	0.169	2nd March, 1935

### Discussion

This method of finding the absorption coefficients is indeed a very simple, efficient and quick one. The drawback of measuring absorption coefficients of materials having a low value, with accuracy, has been partly overcome by using a moving coil galvanometer with the battery type of bridge and a compensating microphone. This whole arrangement is certainly many times more sensitive than those of previous workers, as can be seen by comparing the deflexions and corresponding resistance changes at minima. With a heating current of 28 m amp, Paris<sup>2</sup> obtained a deflexion of 25 divs of the microammeter scale at minima for a material having an absorption coefficient of 26, while Ghosh and Mohammad<sup>1</sup> with a heating current of 37 m amp, obtained a deflexion of 17 mm on a scale for a material having an absorption coefficient of 25. In my case, with a heating current of about 26 m amp, a deflexion as large as 80 mm is obtained, on a scale placed a metre away from the galvanometer, for a material having nearly the same value of absorption coefficient, namely 27. The use of the 'battery type' of bridge instead of the ordinary P. O. Box arrangement, made the conditions of working very steady.

In the apparatus used by others there was no arrangement for keeping the frequency and output of the source constant. These two sources of error were eliminated to a great extent in these experiments.

Although no such elaborate arrangement for minimising the effects of the ground vibrations on the microphone inside the pipe, as mentioned by Paris, was made, yet by working during the holidays at quiet hours, his conditions of working could be approximated to very closely, the more so, because the main roads round the laboratory are quite far away, and there is never such a heavy traffic as those of trams etc on them.

In the case of 'Treetex', four pieces were joined together so as to form a circle, and there was a space of about 2 mm at each joint. This is most probably the reason why its absorption coefficient is so high. Incidentally it throws some light on the value of joints for acoustical purposes.

The most interesting material investigated was an embossed metal plate, obtained by courtesy from Winter Brothers, Calcutta. (These plates painted with various colours, are extensively used in the ceilings of halls and auditoriums.) This plate was given two thick coatings of Lady Brand light blue paint, and dried. The high value of absorption



coefficient, e.g., '25 shows why such halls have generally good acoustical properties provided other factors are also taken into account

Lastly, the fact that almost the same values of absorption coefficients are obtained at different times, and with entirely different conditions of working with the apparatus, places the accuracy of these values beyond doubt

In the end I offer my most sincere thanks to Professor M N Saha for his kind interest and encouragement, and to Dr R N Ghosh for his help and guidance throughout the work

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# ON THE DIRECT FORMATION OF BROMIDES AND THE DISTANCE OF THE CLOSEST APPROACH OF ATOMS OF BROMINE

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Communicated by Prof M N Saha

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In two previous communications<sup>1, 2</sup> it has been shown by the author that the distances of the closest approach of atoms of metals determine their capacity to react with water. It has been shown there that metals whose distances of the closest approach of atoms are above  $3.00\text{\AA}$  can react with water. In subsequent communications<sup>3, 4</sup> the author has pointed out that in the capacity for the formation of amalgams also, the distances of the closest approach of atoms of the metals play a prominent rôle and metals having not less than  $2.5\text{\AA}$  as their values for their closest approach of atoms can form amalgams with mercury, which latter has been shown to have  $2.5\text{\AA}$  as the value of the distance of the closest approach of its atoms. The object of the present communication is to show that the reactivity of elements with bromine also depends upon the distances of the closest approach of atoms of the elements concerned and to arrive at a probable value for the closest approach of atoms in the case of bromine. Further the value so obtained is in accord with that calculated according to the formul aproposed by the author (*loc. cit*)

Bromine is known to react directly with a large number of elements. The following are the cases recorded in literature. The values\* for the distances of the closest approach of atoms of the elements are given within brackets:

Copper (2.54), Gold (2.88), Potassium (4.50), Zinc (2.67), Mercury<sup>4</sup> (2.50), Aluminium (2.86), Tin (2.80), Cobolt (2.514), Iron (2.54), Bismuth (3.47), Molybdenum (2.72), Zirconium (3.18), Calcium (3.93), Magnesium (3.22), Germanium (2.43), Lead (3.48), Indium (3.24), Cerium (3.64), Sulphur (—), Tellurium (—), Chromium (2.508), Antimony (3.37), Thorium (3.54),

\* The values for the distances of closest approach of atoms are taken from Bragg and Bragg's *X-ray and Crystal Structure*, Fifth Edition, p 163.

Silicon (2.35), Sodium (3.72), Tantalum (2.833), Beryllium (—), Rubidium<sup>a</sup> (4.56), Caesium<sup>a</sup> (5.7), Lithium (3.03), Cadmium (2.96), Phosphorus (—), Arsenic (—), Thallium (—), Silver (2.876), Rhodium (2.70), Nickel (2.505), Vanadium (2.64), Titanium (2.96), Selenium (—), Strontium (—)

It will be evident from the above table, that in the case of elements which directly unite with bromine, the distances of the closest approach of their atoms seem to be greater than an approximate figure  $2 \text{ \AA}$ . It has been shown previously (*loc. cit*) that mercury has  $2.5 \text{ \AA}$  as its distance of the closest approach of its atoms as those metals which have atomic approach values greater than  $2.5 \text{ \AA}$  can only react with mercury to form amalgams. Arguing in the same manner we are led to the conclusion that the closest atomic approach value of bromine should in all probability approximate to  $2 \text{ \AA}$ , as the elements having closest atomic approach values greater than the approximate value  $2 \text{ \AA}$  can react with it directly and any element having atomic approach value lower than this approximate figure, for instance, carbon having atomic approach value<sup>a</sup>  $1.54 \text{ \AA}$  or  $1.50 \text{ \AA}$ , has not been found to react with it.

This is further corroborated by the fact that the value for the distance of the closest approach of atoms of bromine as calculated from

the author's<sup>a</sup> formula  $D = \frac{P}{V_i \times d^{k/v}}$  is  $1.73 \text{ \AA}$  (approximating to  $2 \text{ \AA}$ )

which is intermediate between that of silicon, *viz.*,  $2.35$  with which it reacts directly and that of carbon, *viz.*,  $1.54$  or  $1.50$  with which it does not react.

Much like the rule of the reactivity of metals with water (*loc. cit*) and that of the formation of the amalgams with mercury (*loc. cit*) a rule may hence be laid down in the capacity of elements to react directly with bromine that elements with the distances of the closest approach of their atoms above  $1.73 \text{ \AA}$  can only react with bromine. It would thus seem probable that strontium, phosphorus and other elements incorporated in the table, which are known to react directly with bromine, but data for the closest atomic approach values of which seem to be wanting, have values for their closest approach of atoms which are greater than  $1.73 \text{ \AA}$ .

It may be noted also that there seem to be a few exceptions to this rule, *viz.*, platinum, osmium, iridium, ruthenium and palladium which according to the above rule should directly form bromide but no distinctive evidences seem to have been recorded on their direct formation.

<sup>a</sup> Bragg's *X ray and Crystal Structures*, Fifth Edition, p. 163

### CALCULATION OF THE VALUE FOR THE CLOSEST APPROACH OF ATOMS OF BROMINE

The author proposed a formula (*loc cit*) for the calculation of the distances of the closest approach of atoms of elements according to which

$$D = \frac{P}{V_i \times d^{k/v}}$$

where  $D$  is the distance of the closest approach of atoms,  $P$  the parachor,  $V_i$  the ionisation potential,  $d$  the atomic diameter of the element in question and  $k$ , a constant having the value 1.58, and  $v$  is the valency.

For Bromine,

Parachor = 680 (Sugden's *Parachor & Valency*, p. 181)

Ionisation potential = 100 (Hughes & Dixon, *Phys. Rev* (2), **10**, 495, 1917)

Atomic Diameter = 2.38 (Bragg, *Phil Mag* (6) **40**, 169, 1920)

Valency = 1

It will be seen on calculation with the help of the formula, the distance  $D$  of the closest approach of atoms of bromine is 1.73 Å which is intermediate between the value of carbon on the one hand and the silicon on the other

We are therefore led to the conclusions

- (1) Bromine has its closest atomic approach value 1.73 Å
- (2) Elements having their values for the distances of the closest approach of atoms above 1.73 Å are only capable of reacting with bromine

Further elucidation of the problem will be taken up later.

My thanks are due to Prof P Neogi and Prof A. Maitra for their kind interest in the work

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## PHOTOREACTION IN TROPICAL SUNLIGHT

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The subject of photoreaction of organic compounds is one which has attracted the attention of chemists for a long time. A classical case in this respect is perhaps that of chloroform which was shown by Victor Meyer to undergo decomposition in presence of moisture, air and sunlight into carbonyl chloride and hydrochloric acid. The coloration of phenol in presence of air and light was noticed by Gibbs,<sup>1</sup> and De Vres<sup>2</sup> found that aqueous solutions of oxalic, malic and tartaric acids underwent complete decomposition in sunlight if access of air was allowed. Photo-oxidation of polyhydric alcohols has been carried out by De Coninck<sup>3</sup> and Berthelot,<sup>4</sup> that of *p*-phenylenediamine by Baudrowski,<sup>5</sup> of benzaldehyde-phenylhydrazone by Chattaway,<sup>6</sup> of organic dyestuffs of every description by Barat and Dutt.<sup>7</sup> Photo-reduction of ketones to pinacols was studied by Boeseken and Coehn<sup>8</sup> and conversion of benzophenone into benzpinacolone by Gimco.<sup>9</sup> Photo-polymerisation of *p*-vinylanisole was noticed by Toepfer,<sup>10</sup> and of cinnamic acid and unsaturated compounds, in general by Ciamician and Silber.<sup>11</sup> In the same way photo-isomerisation of coumarinic acids and their esters was noticed by Perkin,<sup>12</sup> of substituted ethylenes by Stoermer<sup>13</sup> and of esters of substituted acrylic acids by Rice.<sup>14</sup> From the work of the above authors who are only a few out of the large number that has worked in this field, it is quite evident that sunlight in presence of air very often brings about most profound decompositions of organic substances the nature of which is very often obscure. Sunlight therefore can easily be regarded as one of the most powerful agents for bringing about the decomposition of organic compounds and the present investigation was undertaken in order to elucidate the nature of at least some of the decompositions from a scientific point of view. The following types of compounds were selected for the purpose of examination: aromatic amines, mono- and poly-hydric phenols, diamines, aminophenols and their derivatives,

amino-acids, aldehydes, dyestuffs, aliphatic hydroxy acids, unsaturated acids, heterocyclic compounds, aromatic oximes, phenylhydrazine and sulpho-carbamide. The details of the procedure adopted as well as the results obtained are given in the experimental portion of the paper

### EXPERIMENTAL

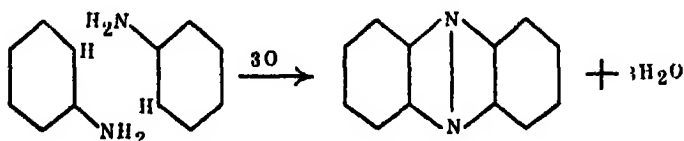
The substances used in connection with the experiments described in this paper were submitted to an exhaustive process of purification, until they were obtained in a state of almost ideal purity. For this purpose repeated distillations under ordinary and diminished pressures, fractional crystallisations from various solvents, sublimations and distillations in steam were resorted to. The pure substances thus obtained were immediately utilised in experiments on photoreaction without storage. For this purpose perfectly clear Jena glass conical flasks of about one litre capacity were filled almost to the neck with solutions of the above-mentioned purified substances in either water, dilute hydrochloric acid, dilute caustic soda or alcohol and after covering the mouths of the flasks with pieces of glazed paper tied loosely so as to allow free access of air, the flasks were fixed in position on a specially erected platform on the high roof of the laboratory where they could get direct sunshine from morning till evening. In this position the flasks were not disturbed save for occasional replenishment of solvent evaporated. They were only removed for examination when profound changes as shown by the formation of large quantities of precipitates, formation of intense colorations, copious evolutions of gases etc had taken place. The strength of the solution employed in most of the cases was 2 per cent.

### Aniline

A 2% solution of this substance in N/5 hydrochloric acid was perfectly colourless in the beginning, but in course of only one day the colour changed to pinkish brown and in two days' time yellow precipitates began to come down. In course of seven days the colour of the solution had changed to deep pink and the quantity of the precipitate went on increasing. At the end of the 26th day the colour of the solution was crimson and on the 42nd day it had changed to vermilion red, the quantity of the precipitate increasing all the time. The precipitates were filtered off from time to time. At the end of the 135th day no further precipitation was observed and the experiment was discontinued.

The precipitate which had a brownish yellow colour was crystallised from alcohol and finally sublimed in glistening yellow needles

melting at  $170^{\circ}$ . It gave an intense violet coloration with concentrated sulphuric acid and had all the properties of phenazine. It was definitely identified to be *phenazine* by a direct comparison with the known substance. The substance must have been formed from aniline in accordance with the following scheme :



The following aromatic amines were then exposed to sunlight in a manner similar to aniline. *Ortho*-, *meta*- and *para*-toluidine, 1,3,4-xylidene, dimethylaniline, *alpha*- and *beta*-naphthylamine, benzidine, *ortho*-nitraniline and nitroso-dimethylaniline. The results are given below:—

*Ortho-toluidine*—gave 1,5-dimethylphenazine and after 120 days no further precipitation occurred. Violet-black microscopic crystals subliming to golden yellow needles melting at  $160^{\circ}$ . (Found N=12.9%)

*Meta-toluidine*—gave 2,6-dimethylphenazine, and precipitation ceased after 71 days. Violet crystals subliming to glistening orange-yellow needles melting at  $156^{\circ}$ . Like the compounds mentioned above, it also gave intense violet colour with concentrated sulphuric acid. (Found N=13.2%)

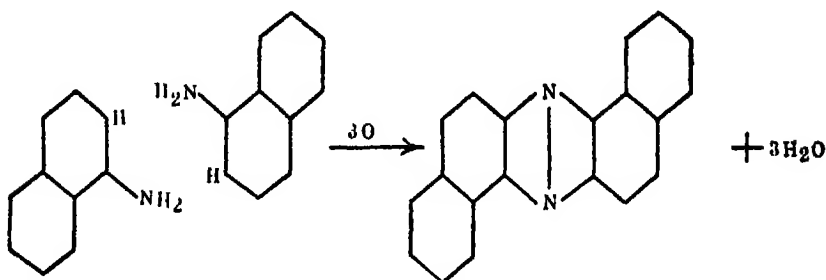
*Para-toluidine*—gave complete precipitation after 123 days' exposure. The dark brown precipitate sublimes in golden yellow needles which decompose without melting on heating. It gave an intense brown-violet colour with concentrated sulphuric acid and was in all probability 3,7-dimethylphenazine although this could not be confirmed for want of authoritative data. (Found N=13.7,  $\text{C}_{14}\text{H}_{12}\text{N}_4$  requires N=13.1%).

*Dimethylaniline*—did not show any perceptible change even after exposure for 141 days and is indeed one of the most stable of organic substances that have yet been examined.

1,3,4-xylidene—gave only a trace of a precipitate after 121 days' exposure and is also a very stable substance. The quantity of the precipitate was too insufficient for chemical examination.

*Alpha-naphthylamine*—gave large quantities of precipitate and after 107 days' exposure the precipitation was almost complete. Dark brown powder subliming on careful heating to reddish brown glistening needles which decompose when heated in a sealed tube without melting. The

substance is undoubtedly  $\alpha\beta$ -dinaphthazine formed in accordance with the following scheme :



(Found N=98 %)

*Beta-naphthylamine*—gave a dark brown precipitate and after 110 days, the precipitation was almost complete. Dark brown crystalline powder subliming in glistening orange-brown needles on careful heating. M P  $240^\circ$ . The substance is undoubtedly  $\beta\beta$ -dinaphthazine formed similarly to the above (Found N=9.6;  $\text{C}_{20}\text{H}_{12}\text{N}_2$  requires N=10.0%)

*Benzidine*—gave a dark coloured precipitate which practically ceased to form after 94 days' exposure. The substance sublimed on careful heating in chocolate-brown glistening needles which did not melt up to  $300^\circ$ . It gave an indigo blue coloration with concentrated sulphuric acid and was undoubtedly a phenazine derivative, but it could not be definitely identified for want of confirmatory data.

*O-nitraniline*—this substance remained absolutely unchanged even after 125 days' exposure and is undoubtedly one of the stablest of organic compounds known.

*p-Nitrosodimethylaniline*—gave complete precipitation after 42 days' exposure. The precipitate which was a yellow crystalline substance, on recrystallisation from alcohol melted at  $220^\circ$  and was found to be identical with *p-nitrosodimethylaniline*.

*p-Nitrosodimethylaniline* in hydrochloric acid solution instead of water as given above, gave a dark brown precipitate which went on accumulating slowly even after 111 days' exposure. It did not melt even at  $300^\circ$  and dissolved in concentrated sulphuric acid with a brown colour and in caustic alkalis with a blackish-brown colour. The substance could not be identified.

#### Mono- and poly-hydric phenols

*Phenol*—in aqueous as well as in alkaline solution on exposure to sunlight at first turned dark red (2 days), then the colour changed to



yellowish brown (6 days) and lastly a brown precipitate began to collect (13 days). This was removed after 64 days' exposure. It crystallises from alcohol in dark brown needles which shrink at 160° but does not melt up to 300°. It dissolves in concentrated sulphuric acid with a dark brown colour and does not give any colour reaction with ferric chloride. It is also insoluble in dilute caustic alkalis. The substance could not be identified.

*Quinol*—gave a small quantity of a black precipitate after 121 days' exposure which had properties somewhat similar to the above. This also could not be identified. On distillation with zinc dust an odour of diphenyl was noticeable.

*Resorcinol*, *Catechol* and *Pyrogallol*—remained practically unchanged even after exposure for 156 days, and are undoubtedly some of the stablest of organic substances.

*$\alpha$ -naphthol*—in caustic soda solution gave a black precipitate which was collected after 78 days' exposure. This does not melt or sublime and is insoluble in all organic solvents as well as in caustic soda. In concentrated sulphuric acid it dissolves partly with a violet-black colour. It could not be identified.

*$\beta$ -naphthol* in caustic soda solution gave a precipitate with properties similar to the above after 80 days. It also could not be identified.

### Aromatic diamines

*O-phenylenediamine*—in one per cent solution in dilute hydrochloric acid began to deposit glistening violet crystals after only 2 days' exposure, and the solution became dark red in colour. The precipitation was complete after 125 days. On careful examination the precipitate was found to be identical with the *hydrochloride of 2:3-diaminophenazine* already prepared and described by Salkowski<sup>15</sup>, Otto Fischer<sup>16</sup> and Wiesinger<sup>17</sup> by different methods.

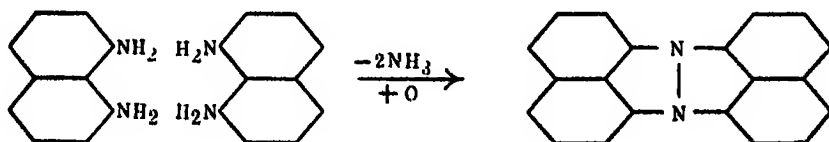
*M-phenylenediamine*—in aqueous solution gave a black precipitate which was collected after 28 days exposure. It crystallised from alcohol and also sublimed on careful heating in violet glistening needles melting at 128°, and was found to be identical with *2:6-diaminophenazine*. (Found N=27.1%).

*P-phenylenediamine*—in dilute hydrochloric acid solution began to deposit a black substance after 5 days' exposure and the precipitate went on increasing till the 106th day, after which it practically stopped. The substance is practically insoluble in all organic solvents except alcohol in which it is slightly soluble, and crystallises from this solvent in

microscopic black needles melting at  $130^{\circ}$ . It seems to be  $\beta$ -6-*diaminophenazine* but this could not be confirmed for want of data (Found  $N=26.8$ ,  $C_{12}H_{10}N_4$  requires  $N=26.6\%$ )

*Dimethyl-p-phenylenediamine*—in dilute hydrochloric acid became of an intense violet colour after an exposure for 120 days, but hardly any precipitation occurred. The solution on investigation was found to contain a dyestuff of the azine series but it could not be definitely identified.

*1,8-naphthalenediamine*—in dilute hydrochloric acid began to deposit a dark brown crystalline substance in course of only two days' exposure and the deposit went on increasing till the 87th day when it was collected in sufficient amount. The substance crystallises from dilute alcohol in dark brown prisms and also sublimes on careful heating in chocolate coloured glistening needles which do not melt up to  $300^{\circ}$ . It dissolved in concentrated sulphuric acid with a violet colour, but was insoluble in dilute acids. Its properties point to its being in all probability *peridinaphthalene-azotide*, formed in accordance with the following scheme:



(Found  $N=9.6\%$ )

*Acetyl-p-phenylenediamine*—in aqueous solution gave a dark orange-brown precipitate in course of only 4 days and the precipitate went on increasing till the 81st day when it was collected. It was crystallised from alcohol in light yellow needles melting at  $239^{\circ}$  and was identified to be *diacetyl-pp'-diamidodiphenylamine*.

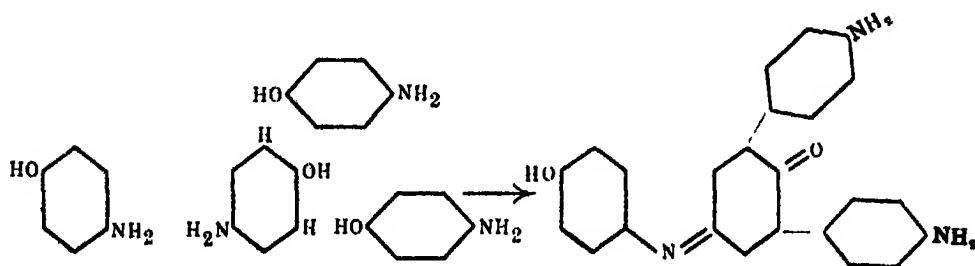
### Aminophenols and their derivatives

*O-aminophenol*—in aqueous solution began to deposit an orange-coloured precipitate in course of only one day's exposure and this went on increasing till the 94th day when it was collected. The substance is easily purified by sublimation when it is obtained in brilliant crimson needles with a silky lustre. It dissolves in concentrated sulphuric acid with an indigo-blue colour and does not melt up to  $300^{\circ}$ . The product is identical with the compound  $C_{12}H_{11}N_3O_2$ , described by G. Fischer<sup>16</sup> and this was further confirmed by analysis (Found  $N=11.0$ ;  $C_{12}H_{11}N_3O_2$  requires  $N=10.9\%$ )

*M-aminophenol*—in aqueous solution began to deposit a brown precipitate after 6 days' exposure and the precipitate was collected after

62 days The substance is practically insoluble in all organic solvents and therefore could not be crystallised from any one of them It however sublimed on careful heating in small quantities as an orange-brown acicular needle like aggregates which did not melt up to 300° The substance could not be identified

*P-aminophenol*—in aqueous solution began to give a black precipitate after 6 days' exposure and the precipitate was collected after 70 days. The substance is easily soluble in alcohol and most of the organic solvents with an intense violet colour and from the alcoholic solution it is obtained in shining violet needles which do not melt up to 300° It dissolves in concentrated sulphuric acid with an indigo blue colour and the same colour is also obtained with strong hydrochloric and glacial acetic acids The reactions as well as the analysis of the substance point to the conclusion that it must be *pp-dihydroxy-diaminino-endorphenol* formed in accordance with the following scheme



(Found  $\text{N}=11.4$ ,  $\text{C}_{14}\text{H}_{18}\text{N}_2\text{O}_2$  requires  $\text{N}=10.9\%$ )

*Dimethyl-m-amidophenol*—gave only a trace of a precipitate after exposure for 125 days and is undoubtedly a very stable organic substance since it was recovered practically completely unchanged after that period

*Dimethyl-p-amidophenol*—behaved exactly similarly to the above-mentioned compound

*O-anisidine*—in dilute hydrochloric acid became dark red after 4 days' exposure and in about 10 days a precipitate began to collect at the bottom This went on increasing till the 78th day when it was collected The substance crystallised from alcohol and also sublimed in orange-brown needles which do not melt up to 300°. It dissolves in concentrated sulphuric and hydrochloric acids with an intense indigo-blue colour and from the solution the substance is reprecipitated unchanged on dilution. The substance has been identified to be *1:5-dimethoxyphenazine*. (Found  $\text{N}=11.2$ ;  $\text{C}_{14}\text{H}_{12}\text{N}_2\text{O}_2$  requires  $\text{N}=11.6\%$ ).

*P-anisidine*—in hydrochloric acid solution behaved in a similar manner to the above compound and the product which sublimed in orange-brown needles and gave indigo-blue colour with concentrated sulphuric acid was identified to be *3 7-dimethoxy-phenazine* (Found N=11 4 %).

*O-phenetidine*—behaved similarly and gave *1 5-diethoxy-phenazine*.

*P-phenetidine*—also behaved similarly and gave *3 7-diethoxy-phenazine*

*2 4-diamido phenol*—in aqueous solution began to give a black precipitate in course of 7 days and the precipitate was collected after 63 days. The substance crystallises from alcohol in shining black needles which do not melt up to 300° and is very slightly soluble in most of the organic solvents. It gives a violet colour with concentrated sulphuric acid and crimson colour with acetic acid. The substance appears to be a derivative of phenazine but it could not be identified for want of confirmatory data.

### Aromatic amino-acids

*Anthranilic acid*—in dilute hydrochloric acid solution became orange-red after 6 days' exposure and in ten days' time a dark coloured precipitate began to collect at the bottom. This was removed after 120 days' exposure and had the following properties. It crystallised from alcohol in yellow needles melting above 300°. It dissolved in sodium bicarbonate solution with effervescence and gave an orange-red colour with concentrated sulphuric acid. It was identified to be *phenazine-1 5-dicarboxylic acid*. (Found N=9 9,  $C_{14}H_8O_4N_2$  requires N=10 4 %)

*P-aminobenzoic acid*—in dilute caustic soda solution became crimson-red after exposure for seven days, but the colour gradually faded and became light brown after two months. A colourless shining crystalline precipitate began to deposit after 10 days and this was collected after 85 days. On examination this was found to be the *disodium salt of pp'-azobenzene-dicarboxylic acid*. The free acid melted above 300° C and the diethylester at 114°.

*M-aminobenzoic acid*—in dilute caustic soda solution was practically unchanged after exposure for 125 days and is indeed a very stable substance.

### Aromatic aldehydes

*Vanillin*—in dilute caustic soda solution was practically unchanged after an exposure of three months.

*Beta-resorcyllaldehyde*—in dilute caustic soda solution behaved similarly to the above.

*P-dimethyaminobenzaldehyde*—in aqueous solution was unchanged even after three months

*P-aminobenzaldehyde hydrochloride*—in aqueous solution began to give a yellow precipitate after 10 days' exposure and the precipitate was collected after 123 days. The substance crystallised from dilute alcohol in brown-yellow needles melting at 239° and was identified to be *pp'-di-aldehyde-azobenzene*

### Miscellaneous compounds

*Rosin*—in 1% aqueous solution took nearly 75 days for complete decolorisation. A shining crystalline deposit which was formed on recrystallisation from water melted at 218° and was found to be identical with *2,4-dibromo-1-benzoylbenzoic acid*. The mother liquor contained good amounts of hydrobromic acid and gave a precipitate of silver bromide on treatment with silver nitrate in dilute nitric acid.

*Erythrosin*—in 1% aqueous solution took nearly 120 days for complete decolorisation. A shining crystalline deposit which was formed did not melt without decomposition and was probably *2,4-diiodo-1-benzoylbenzoic acid* by analogy, but this could not be confirmed for want of data. In the mother liquor good amounts of free hydriodic acid were also found.

*P-aminoacetophenone*—in dilute hydrochloric acid turned reddish brown in course of only one day and in a week's time an orange-brown precipitate began to deposit. This was collected after 75 days. It crystallises from alcohol in yellow-brown needles melting at 180°, reduces ammoniacal silver nitrate and gives an orange-brown colour with concentrated sulphuric acid. It could not be identified.

*Gallacetophenone*—in dilute caustic soda solution was altogether unaffected even after exposure for 90 days. A very stable substance.

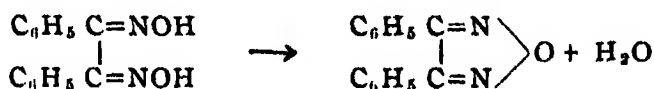
*Phenylhydrazine*—in aqueous solution become yellow and turbid in course of only one day's exposure and brisk evolution of gas (nitrogen) took place. In seven days' time a yellow-brown deposit was formed and this was collected after 56 days. The substance crystallises from alcohol in brownish yellow needles melting at 128° and contains nitrogen. It does not reduce Fehling's solution and is insoluble in dilute acids, alkalis and does not get diazotised or in any way affected by nitrous acid. It dissolves in strong sulphuric acid with a brown colour. The substance which apparently is a heterocyclic compound could not be identified.

*2-amidothiazole*—in dilute hydrochloric acid gave only a trace of a precipitate after exposure for three months which gave colour reactions

of phenazine derivatives. The quantity was too insufficient for further examination

*Sulpho-carbamide*—in aqueous solution became turbid after one day's exposure and a precipitate began to deposit fairly freely in course of a week. After exposure for 46 days the precipitate was collected and crystallised from carbon disulphide in fine yellow rhombic prisms melting at  $225^{\circ}$ . It was identified to be pure *sulphur*. The mother liquor was found to contain *carbamide*.

*Benzil- $\alpha$ -dioxime*—in dilute caustic soda solution in course of only ten days began to deposit colourless feathery crystals in large quantities and these were collected after 35 days. The substance was recrystallised from alcohol and melted at  $94^{\circ}$ . On examination the substance was found to be identical with 3,4-diphenyl-furazan, formed in accordance with the following scheme



### Geometrical inversion

*Maleic acid*—in 1 % aqueous solution after exposure for 50 days was found to be completely converted into *fumaric acid*. No other product could be detected.

*Cinnamic acid*—in the form of its neutral sodium salt in 1 % aqueous solution after 50 days' exposure was found to be converted partially (17.2%) into *allo-cinnamic acid* which was separated from the excess of cinnamic acid by fractional crystallisation from water. The substance melted at  $67.5^{\circ}$ .

*Itaconic, citraconic and tiglic acids* in aqueous solution remained unchanged even after 75 days' exposure, no geometrical inversion being noticeable in these cases.

*Oleic and brassidic acids*—in the form of sodium salts in aqueous solution became somewhat turbid after exposure for 50 days but no chemical change could be observed on examining the solutions.

*Erucic acid*—in dilute alcohol began to deposit a colourless precipitate in course of only 5 days and this went on increasing till the 38th day when it was collected. The substance crystallises from alcohol in colourless prisms melting at  $118^{\circ}$  and was found to be identical with *dihydroxyerucic acid*.

### Aliphatic hydroxy acids

*Malic acid*—in one per cent aqueous solution was found to develop spores after only two days' exposure. The solution was therefore sterilised by boiling and the mouth of the flask covered with sterile cotton. After exposure for 123 days the solution was distilled and the strongly acid distillate on repeated extraction with ether and subsequent evaporation of the solvent gave a thick pale yellow liquid which gave all the reactions of *pyruvic acid*. It reduced Fehling's solution and ammoniacal silver nitrate, gave a yellow precipitate with phenylhydrazine and an insoluble lead salt. Pure pyruvic acid was obtained by decomposing the latter compound.

*Citric acid*—in aqueous solution after sterilisation underwent no change even after exposure for four months.

*Tartaric acid*—in aqueous solution was exposed for four months and then the solution was distilled. The neutral distillate on extraction with ether gave a minute quantity of a crystalline solid with strong aldehydic or ketonic properties. The quantity was however too insufficient for chemical examination. From the residue practically the whole of the tartaric acid was recovered unchanged.

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## SOME ASPECTS OF NITROGEN FIXATION IN SOIL

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In a previous paper<sup>1</sup> it was shown that the ammonia content of soils is appreciably increased when energy-rich compounds like sugar, molasses, etc are added to the soil, which has been properly aerated after the addition of sugars or molasses. Further work in this line is necessary as authorities in agriculture are still doubtful whether nitrogen fixation is possible in soil by the addition of energy-rich compounds. This is evident from the following lines<sup>2</sup> :—

“In view of the fact that the energy added to the soil is not directly available to the nitrogen fixing bacteria, and that small amounts of available nitrogen is always present in the soil, and the error in the laboratory determination of total nitrogen by Kjeldahl method is greater than the possible amount of nitrogen fixed by nonsymbiotic bacteria, we are still unable to decide the question definitely. Until our methods are more accurate, the question cannot be answered in a positive way. It has been stated, that the apparent gain of nitrogen in the soil is often due to drifting dust and plant residues or to soil variability.” Exactly similar views have also been expressed by Russell<sup>3</sup>

Moreover, upto now it has been universally accepted that the nonsymbiotic nitrogen fixation in the soil is entirely a bacterial process, caused by the activity of azotobacter, clostridium etc. Our results, however, show definitely that even in the complete absence of bacteria under sterilized conditions, the oxidation of sugars by air leads to the formation of ammonia specially in presence of sunlight.

The experimental results recorded in the following tables, can be divided into four sets

In the first set the soil has been mixed with different amounts of cane sugar or molasses and exposed to sunlight and air in enamelled dishes covered with ordinary glass plates. For the experiments in the dark the outer surface of the glass plates is covered with a thick coating of Japan-black enamel.



In the second set of experiments, known weights of molasses have been added to a definite area of soil, which has been carefully aerated by frequent turning over

In the third set, weighed amounts of soil have been mixed with definite weights of molasses and made into heaps and exposed to air and light. For better aeration the heaps were frequently stirred. From time to time the total, ammoniacal and nitric nitrogen in 50 g of the soil were estimated from all these sets. The results obtained have been expressed in grams per 100 g. of the soil.

In the fourth set of experiments, carefully sterilised soil (sterilisation effected in an autoclave under 20 lb pressure for 2½ hours) has been mixed with sterilised cane sugar and exposed to sunlight in quartz flasks and tubes with plugs of sterilised cotton wool for definite periods and the whole of the soil analysed for its ammoniacal, nitric and total nitrogen content after the necessary exposure.

#### METHOD OF ANALYSIS

For estimating the ammoniacal nitrogen present in the soil, 50 g. of the soil, which were dried in a steam oven, were treated with 5 g of pure KCl and 5 g of pure magnesium oxide and about 50 c.c. of water and distilled for six hours on a water bath, and at the same time a current of air purified by passing through a solution of ferrous sulphate, was aspirated. The ammonia was absorbed in two flasks containing standard solutions of sulphuric acid.

For the estimation of nitric nitrogen the soil, from which ammonia has been removed by the previous procedure, was treated with 1 g of Devarda's alloy free from ammonia and nitrate and 25 c.c. of 1% sodium hydroxide and left overnight for the reduction of nitrite and nitrate to ammonia. When the reduction was complete, the ammonia set free was estimated as in the first stage.

The total nitrogen was estimated according to the method of Robinson, McLean and Williams<sup>4</sup> by heating 5 g. of well dried and powdered soil with 20 c.c. concentrated sulphuric acid, 5 g. fused potassium sulphate and a few crystals of copper sulphate for four hours. The ammonium sulphate thus formed was estimated as before.

The sum of the ammoniacal and nitric nitrogen is known as *total available nitrogen* and the nitrogen obtained, according to the modified Kjeldahl method is the *total combined nitrogen*.

In all these experiments, the laboratory garden soil from the same locality was used.

The following results have been obtained —

*A Experiments with cane sugar and soil in dishes*

The cane sugar used in the experiments did not contain any combined nitrogen

		Ammonia- cal nitro- gen	Nitric nitrogen	Total available nitrogen	Ammonia- cal nitro- gen	Nitric nitrogen	Total available nitrogen
		UNSTERILISED			STERILISED		
Exposure for 78 hours spread over 13 days	250 g soil alone	0.00192%	0.002%	0.00392%	0.00224%	0.0024%	0.00464%
	20 g sugar and 250 g soil	0.00497	0.002	0.00697	0.00208	0.00224	0.00492
	20 g sugar and 10 g $\text{Na}_2\text{HPO}_4$ and 250 g soil	0.00267	0.0038	0.00656	0.00224	0.00224	0.00448
	20 g sugar, 10 g $\text{Na}_2\text{HPO}_4$ 5 cc 1% $\text{FeCl}_3$ and 250 g soil	0.00384	0.00218	0.00602	0.00208	0.00224	0.00492
Exposure for 147 hours spread over 28 days	250 g soil alone	0.00168	0.00234	0.00402	0.00238	0.00254	0.00492
	20 g sugar and 250 g soil	0.01444	0.0025	0.01694	0.0094	0.00254	0.01194
	20 g sugar, 10 g $\text{Na}_2\text{HPO}_4$ and 250 g soil	0.0162	0.0024	0.01864	0.00888	0.00242	0.0113
	20 g sugar, 10 g $\text{Na}_2\text{HPO}_4$ 5 cc 1% $\text{FeCl}_3$ and 250 g soil.	0.00886	0.0024	0.01126	0.0142	0.0024	0.0166
	Ditto in the dark	0.007	0.00258	0.00958	0.00284	0.0025	0.00514
	250 g. soil alone in dark.	0.00165	0.00246	0.00411	0.0025	0.00256	0.00506

		Ammonia- cal nitrogen	Nitric nitrogen	Total available nitrogen	Ammonia- cal nitrogen	Nitric nitrogen	Total available nitrogen
		UNSTERILISED			STERILISED		
Kept for 230 hrs spread over 48 days.	250 g soil alone	0.00169	0.00222	0.00392	0.00206	0.00242	0.00448
	20 g sugar and 250 g soil	0.01296	0.00264	0.0156	0.00792	0.0025	0.01042
	20 g sugar and 10 g $\text{Na}_2\text{HPO}_4$ and 250 g soil	0.01224	0.00264	0.01488	0.00626	0.00321	0.00947
	20 g sugar, 10 g $\text{Na}_2\text{HPO}_4$ , 5 c.c. 1% $\text{FeCl}_3$ and 250 g soil	0.01221	0.00264	0.01488	0.00626	0.00322	0.00948
	Ditto in the dark	0.0064	0.00258	0.00898	0.00246	0.00258	0.00504
	250 g soil alone in dark	0.00172	0.00226	0.00398	0.0025	0.00224	0.00474
	250 g soil alone	0.00172	0.0024	0.00412	0.00185	0.00254	0.00439
	250 g soil and 20 g sugar	0.00642	0.00584	0.01226	0.00244	0.0025	0.00494
	20 g. sugar, 10 g. $\text{Na}_2\text{HPO}_4$ and 250 g soil.	0.00604	0.00474	0.01078	0.00284	0.00246	0.0053
	20 g. sugar, 10 g. $\text{Na}_2\text{HPO}_4$ , 5 c.c. 1% $\text{FeCl}_3$ and 250 g. soil.	0.00582	0.00578	0.0116	0.00244	0.00224	0.00468
Kept for 68 days.	20 g. sugar, 10 g $\text{Na}_2\text{HPO}_4$ , 5 c.c. 1% $\text{FeCl}_3$ and 250 g soil (dark).	0.0062	0.00558	0.0137	0.00246	0.00258	0.00504
	250 g. soil alone in dark.	0.00178	0.00226	0.00404	0.00244	0.00224	0.00468

*B Experiments with molasses and soil in dishes*

In the following table corrections have been applied for the amount of ammonia introduced with molasses —

(The molasses contained 0.001% ammoniacal nitrogen and no nitric nitrogen)

Amount of molasses added per kilogram soil		Ammoniacal nitrogen	Nitric nitrogen	Total available nitrogen	Total combined nitrogen
Exposure 76 hours	Original	0.000734%,	0.0035/,	0.00423/,	0.03627
	5 g	0.000738,	0.001,	0.004738,	0.0362
	10 g	0.00072,	0.001,	0.00472,	0.0362
	20 g	0.000725,	0.004,	0.00472,	0.0362
	40 g	0.00071,	0.001,	0.004708,	0.0362
	75 g	0.0014,	0.004,	0.0074,	0.0398
	100 g	0.00134,	0.004,	0.00534,	0.0473
	150 g	0.00112,	0.004,	0.00512,	0.05
	190 g	0.00102,	0.001,	0.00502,	0.053
Exposure 161 hours	5 g	0.000944,	0.004,	0.004944,	0.036
	10 g	0.00096,	0.0038,	0.00476,	0.036
	20 g	0.00106,	0.0038,	0.00486,	0.036
	40 g	0.00113,	0.0038,	0.00493,	0.036
	75 g	0.0022,	0.0038,	0.006,	0.038
	100 g	0.00222,	0.0038,	0.00602,	0.046
	150 g	0.00216,	0.0038,	0.00596,	0.049
	190 g	0.0021,	0.0038,	0.0059,	0.052
Corresponding in dark	10 g	0.00111	0.00338	0.00448	0.0362
	20 g	0.00097,	0.00376,	0.00475,	0.0362
	40 g	0.00043,	0.00376,	0.00410,	0.0362
Exposure = 279 hours	5 g	0.00136,	0.00412,	0.00548,	0.036
	10 g	0.00148,	0.00412,	0.0056,	0.036
	20 g	0.00159,	0.00412,	0.00571,	0.036
	40 g	0.00184,	0.00412,	0.00596,	0.0362
	75 g	0.0022,	0.004,	0.0062,	0.0382
	100 g	0.002,	0.00324,	0.00524,	0.046
	150 g	0.00104,	0.00284,	0.00388,	0.0492
	190 g	0.00037,	0.00234,	0.00261,	0.0527
Corresponding in dark	10 g	0.00074,	0.00324,	0.00398,	0.036
	20 g	0.00051,	0.0031,	0.00361,	0.036
	40 g	0.000414,	0.00282,	0.00323,	0.036

Plots of land of area 36 sq ft were treated with 1½, 3 and 6 kilograms of molasses. The following table shows the nitrogen content of the soil at various periods. It has been found by analysis that the control field does not indicate any appreciable increase in the nitrogen content during the time taken up by these experiments.

*C Experiments with molasses added to field soil*

With 1½ kilograms of molasses per 36 sq ft. Analysis of the molasses.—

	Ammoniacal nitrogen. 0.001%	Nitrate nitrogen ml			
	Ammoniacal nitrogen	Nitric nitrogen	Total available nitrogen	Total combined nitrogen	Analysed on
Original	0.00216%,	0.00232%,	0.00448%,	—	
Aeration with molasses after 15 days	0.00312,	0.00242,	0.00554,	0.0417,	17-2-1935
Aeration with molasses after 30 days	0.00608/,	0.0052/,	0.01128/,	0.0409/,	4-3-1935
Aeration with molasses after 45 days.	0.00842,	0.00574,	0.01216,	0.0437,	20-3-1935

With 3 kilograms of molasses per 36 sq feet.

Original	0.00062,	0.0069,	0.00752,	0.0434,	22-12-1934
Aeration with molasses.	0.00062,	0.0069,	0.00752,	0.0618,	9-1-1935
Insufficient aera- tion.	0.00062,	0.0069,	0.00752,	0.0455,	„

	Ammoniacal nitrogen	Nitric nitrogen	Total available nitrogen	Total combined nitrogen	Analysed on
With 3 kilograms of molasses per 36 sq feet					
Aeration with molasses	0.00086,	0.00864,	0.00950,	0.0619,	24-1-1935
Insufficient aera- tion	0.00046,	0.00682,	0.00728,	0.0442,	"
Aeration with molasses	0.001,	0.00932,	0.01032,	0.061,	8-2-1935
Insufficient aera- tion.	0.00043,	0.0065,	0.00693,	0.045,	"
Aeration with molasses	0.00156,	0.0092,	0.01076,	0.062,	24-2-1935
Insufficient aera- tion	0.00042,	0.0064,	0.00682,	0.046,	"
Aeration with molasses	0.00182,	0.00929,	0.01111,	0.062,	10-3-1935
Insufficient aera- tion	0.00052,	0.0064,	0.00692,	0.046,	"
Aeration with molasses	0.00182,	0.0092,	0.01102,	0.0646,	26-3-1935
Insufficient aera- tion	0.00068,	0.00648,	0.00716,	0.041,	"
With 6 kilograms of molasses per 36 sq feet.					
Original	0.007,	0.00854,	0.01544,	0.0432,	2-2-1935
Aeration with molasses	0.00875,	0.00784,	0.01659,	0.0458,	17-2-1935
Ditto	0.01186,	0.0076,	0.01946,	0.045,	4-3-1935
Ditto	0.01058,	0.00724,	0.01782,	0.0472,	20-3-1935

*D Molasses added to soil in heaps*

A heap of soil weighing 167 kilograms (A) was treated with 12 kilograms of molasses, and another heap weighing 174 kilograms (B) was treated with 6 kilograms of molasses and frequently stirred after adding small amounts of water

	Ammoniacal nitrogen	Nitric nitrogen	Total available nitrogen	Total combined nitrogen
Original Treated with molasses on 18-2-1935	0.00865%,	0.00582%,	0.01447%,	0.0458%
A analysed on 18-3-1935	0.01646,	0.00594,	0.0224,	0.0538
B " "	0.00934,	0.00594,	0.01528,	0.0504
A analysed on 18-4-1935	0.01400,	0.0058,	0.0198,	0.0540,
B " "	0.0116,	0.0058,	0.0174,	0.0512

*E. Experiments with cane sugar and soil in sterilised condition*

Original	0.00155,	0.0035,	0.00505,	
Soil 50 g + Cane sugar 4g Exposure 60 hrs. in 250cc quartz flask	0.00233,	0.004,	0.00633,	
Soil 50 g. + Cane sugar 2 g Exposure 150 hrs in 250cc quartz flask.	0.0056,	0.0042,	0.0098,	
Soil 50 g + 1 g $\text{Na}_2\text{HPO}_4$ + Cane sugar 4 g. Exposure 150 hrs. in 250cc quartz flask.	0.00468,	0.00442,	0.0091,	
Soil 50 g + Cane sugar 4g + 1g $\text{Na}_2\text{HPO}_4$ Exposure 302 hrs. in quartz test tube.	{ 0.00102, 0.00127,	0.0035, 0.00462,	0.00452, 0.00589,	before the ex- posure after the ex- posure

	Ammoniacal nitrogen	Nitric nitrogen	Total available nitrogen	Total combined nitrogen.
Original	0.000734%,	0.0035%,	0.004234%,	0.00458%,
Soil 100 g. + water 50c.c. + cane sugar 1 g. Exposure 145 hrs in 250c.c. quartz flask	0.00116,	0.00402,	0.00518,	0.0466
Soil 100 g. + sugar 2 g. + water 50c.c. Exposure 284 hrs in 250c.c. quartz flask	0.00155,	0.00386,	0.00541,	0.0486
Ditto with 4 g. sugar	0.00175,	0.00386,	0.00561,	0.0486

The results recorded in the foregoing tables show that in all cases, when either cane sugar or molasses are added to the soil, which is properly aerated, there is an appreciable increase in the ammonia content. The amount of ammonia goes on increasing to a limiting value with the increase of exposure. The nitrate content also increases with time, specially in aerated soils. When the exposure is continued further, denitrification sets in. It is interesting to note here that previous workers, determined only the total nitrogen of the soil after the addition of energy-rich compounds, and as the difference in the total nitrogen is not high before and after the addition of the energy-rich compounds to the soil, they were doubtful regarding the fixation of nitrogen in the soil by the addition of energy-rich compounds. But as we have estimated, both the available (ammoniacal and nitric nitrogen) and the total nitrogen, we have been able to detect the increase of available nitrogen in all cases when energy-rich organic compounds are added to well aerated soils.

Another far-reaching conclusion can be drawn from our experimental results, which show, that under identical conditions, the amount of ammoniacal nitrogen is always greater in the soil mixed with energy-rich compounds and receiving sunlight, than in the dark. If this type of nonsymbiotic nitrogen fixation had been entirely a bacterial process as has been generally believed, the amount of ammonia formed should not differ in the vessels kept in light or in the dark. Moreover, the results obtained in the sterilised condition show an increase in ammonia, when the soil is mixed with cane sugar and exposed to sunlight under



completely sterilised conditions. It seems established, therefore, that just as bacteria can fix nitrogen in the soil in presence of energy-rich compounds, similarly even in the absence of bacteria, the photo oxidation of the energy-rich compounds, leads to the fixation of nitrogen. It appears, therefore, that in tropical countries in ordinary soils the fixation of atmospheric nitrogen by the addition of energy-rich compounds is partially bacterial and partially photo-chemical. The oxidation of energy-rich organic compounds by air either by light absorption, or by bacterial action causes the fixation of atmospheric nitrogen in the soil. The recent experiments of Dhar and Mullik on the influence of temperature on nitrogen fixation by a fairly pure culture of *azotobacter* thriving in mannitol medium, as the energy-rich substance show the optimum temperature for nitrogen fixation to be 35° as will be evident from the following results obtained at different temperatures —

Temperature — (ammonia formed in milligrams)

Days	0°	15°	25°	30°	35°	40°
4	nil	1.28	2.41	3.21	4.11	6.88
8	"	2.61	4.36	6.53	7.79	10.61
12	"	4.13	6.80	8.76	11.76	12.1
16	"	5.01	8.93	11.75	14.3	14.5
20	"	6.2	11.15	14.5	17.13	14.86
24	"	7.18	12.81	16.45	19.45	15.17
28	"	8.01	14.83	18.11	21.17	15.29
32	"	8.89	15.61	18.76	22.79	15.33
36	"	9.85	16.5	19.01	22.91	15.31

It appears, therefore, that in the tropical countries in summer months, when the soil temperature is as high as 70° nonsymbiotic nitrogen fixation in presence of energy-rich compounds may be more of a photo-chemical nature than of bacterial.

There is a practical aspect of these investigations, because very little definite knowledge is available regarding the amounts of nitrogen that can be fixed in nonsymbiotic process. Miller<sup>5</sup> has stated the problem in the following words:—

"Wide use is being made in systems of agriculture of the bacteria, which work with legumes, but the nitrogen fixing power of those which work outside the plant is as yet not utilised extensively by man, since the methods of controlling them are not well understood."

In many of our field experiments the amounts of ammoniacal nitrogen was three times greater when molasses have been added and the soil

aerated than that was originally present in the soil. From a simple calculation it can be shown that the amount of nitrogen added to the soil in this way can be 152.4 kilograms per acre which is equivalent to the addition of 356 kilograms of ammonium sulphate when only 0.0001% fixation occurs.

Our results show that increased aeration leads to an increase in the ammonia content of the soil mixed with the cane sugar or molasses. Moreover, we have observed ammonia formation when air is passed through a solution of glucose or cane sugar mixed with an inductor like ferrous or cerous hydroxide. The induced oxidation of cane sugar or glucose liberates energy which is utilised in the fixation of nitrogen.

We are of opinion that the energy set free in the oxidation of energy rich compounds by air either through the agency of bacteria (azotobacter), or sunlight or inductors is utilised in the following endothermic reaction  $N_2 + O_2 = 2 NO - 43.2 \text{ Cal}$ . The nitric oxide is further oxidized to nitrate which seems to be the first product in nitrogen fixation. The iron compounds present in the soil help this oxidation. Recently Dhar and Mukerji<sup>6</sup> have shown that nitrates and carbohydrates (but not ammonium salts and carbohydrates) in presence of sunlight and  $TiO_2$  can readily form amino acids with copious production of ammonium salts. Hence the nitrate, which is likely to be the first product in nitrogen fixation in soil in presence of air, is reduced to ammonia by the action of carbonaceous substances with the simultaneous formation of amino acids in small amounts and that is why ammonia is observed in nitrogen fixation. Waywick and Woodhouse<sup>7</sup> have also obtained evidence of amino acid formation in nitrogen fixation in soils.

The recent work of Burk<sup>8</sup> seems also to be in favour of the view that nitrate and not ammonia is the first product in nitrogen fixation.

### SUMMARY

1. When cane sugar is added to sterilised and unsterilised soils and exposed to light and air, there is appreciable increase in the ammoniacal nitrogen content; with unsterilised soil the ammoniacal nitrogen is nine times greater than that originally present in the soil.

The amount of  $NH_3$  in presence of light is always greater than that in the dark.

2. By the addition of molasses to soils, which have been properly aerated the ammoniacal nitrogen also increases; in this case the ammoniacal nitrogen is three times greater than that originally present in the soil, when 3600 kilograms of molasses are added per acre of land. When the

aëration of the soil is insufficient the increase of ammonia is less and the soil becomes acidic

3. Under completely sterilised conditions when cane sugar is mixed with soil, there is also an increase in the ammoniacal nitrogen. The total available nitrogen (ammoniacal and nitrate nitrogen) in the soil was 0.005, but after exposure to sunlight in a quartz flask with cane sugar it became 0.0098. It seems established therefore, that just as bacteria can fix nitrogen in the soil in presence of energy-rich compounds, similarly even in the absence of bacteria, the photo-oxidation of the energy-rich compounds, leads to the fixation of nitrogen

It appears, therefore, that in tropical countries in ordinary soils, the fixation of atmospheric nitrogen by the addition of energy-rich compounds is partially bacterial and partially photo-chemical. The oxidation of energy-rich organic compounds by air either by induction or light absorption, or by bacterial action, causes the fixation of atmospheric nitrogen in the soil

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# ON EIGHT NEW SPECIES OF THE GENUS *CYCLOCOELUM* BRANDES FROM NORTH INDIAN SNIPES\*

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## Introduction

So far not a single species of the genus *Cyclocoelum* has been recorded from India. In July 1932 Dr. H. R. Mehra suggested to me to examine the snipes available at Allahabad for collection and investigation of different members of the family Cyclocoelidae. Accordingly I dissected more than hundred snipes and obtained a large number of specimens belonging to eight new species of the genus *Cyclocoelum* which are described in this paper. The worms are exclusively parasitic in the air sacs or the body cavity. Some immature forms, however, were found in the small intestine of the hosts. The degree of infection varies considerably in different periods of the year in various species of the host birds which belong to the family Scolopercidae. The snipes first appeared infected in the month of September when the largest number of parasites obtained from a single host was only three and the rate of infection only thirty per cent. The rate and degree of infection increase from September onwards, reaching the maximum in November when as many as fifteen worms were obtained from a single snipe, and the rate of infection reached sixty per cent. *Glossus nebularius*, the common green shank known as "Chaha" is the most favourable host for a large number of species of *Cyclocoelum*. Though the degree of infection is not very high, a large number of birds are found infected with as many as four different species. *Capella gallinago gallinago*, the common fan tail snipe, known as "Chahe" is another bird which is found commonly infected.

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The infection in this case appears rather early in the year and the maximum rate is sixty per cent; but never more than five specimens of *Cyclocoelum* were obtained from a single host. In *Tringa erythropus*, the common dusky red shank, known as "Lal tang ka chaha" the infection is very rare, from it only two specimens were obtained and less than thirty per cent of these birds were found infected, but the infected birds always yielded quite a large number of specimens. As many as fifteen specimens were obtained from a single host. The parasites could not live for more than six hours in normal salt solution or nutritive solutions.

I am much indebted to Dr H R Mehra under whose supervision this work was carried on. He not only suggested the problem and guided me in this work but he was also kind enough to translate the papers in French for me. I have great pleasure to acknowledge my sincerest thanks to him. I am also indebted to Dr D. R. Bhattacharya for giving me facilities in the department to carry on this work. My thanks are also due to Mr S C Verma for his kind help and permission to work up part of the material already in his possession.

### Previous work on the Family Cyclocoelidae Kossack, 1911

In 1782 Goeze described two species which he believed to have only one sucker. Schrank (1788) published a paper which was a mere catalogue of the species. If we do not take into account these two workers, Zeder (1800, 1803) was the first who studied the group thoroughly and used the name Monostome for these parasites on account of the absence of the ventral sucker. In 1801 he gave the first account of *C. mutabile*, the type species of the genus *Cyclocoelum*. The group of monostomes which formed a main division in the classification of the Digenea, called Monostomata is maintained even now by many workers on the group, though its validity has been well criticised by several recent authorities. Zeder assigned five species, i.e., *M. ocreatum*, *M. bombynae*, *M. verrucosum*, *M. prismaticum* and *M. mutabile* to this then newly created group Monostomata. Later on the first two were removed to the Distomata; third was grouped under the sub-family Notocotylinæ while the last two were assigned to the sub-family Cyclocoelinae.

Rudolphi in 1808 in his synopsis Entozoorum agreed with Zeder in the system of classification which he adopted and described the anatomy of *M. ellipticum* obtained from the lungs of *Rana maculata*. Von Siebold (1835) gave the first complete description of these monostomes and described *M. mutabile* Zeder, 1801, giving an

account of early stages of its life-history as seen in the egg before it is discharged from the uterus. Diesing, 1850, reorganised this group including all the species known upto that time. Von Beneden, 1861, worked out the anatomy of *M. verrucosum* Frolich reviewing the anatomy of *M. mutabile* Zeder, 1801, and described a cercaria which he considered to be the larval form of *M. verrucosum* Frolich.

Monticellie's work in 1892 published in two papers gave an account of the genus *Notocotyle* Diesing, 1850, and *M. cymbium* Diesing, 1850.

Brandes in 1892 was the first to propose the genus *Cyclocoelum* to include *M. mutabile* Zeder, *M. flavum* Mehlis, *M. tringae* Brandes, *M. ellepticum* Rudolphi and *M. arcuatum* Brandes and gave its diagnosis. Looss in 1899 accepted this genus with *M. mutabile* as the type species. But his contemporary Lühe in 1900 in his review of the work of Looss did not accept the generic name *Cyclocoelum* because the family name Monostomidae could not be used without a type genus Monostoma according to the rules of nomenclature. Looss in 1901 explained that *M. prismaticum* was the type of the genus Monostoma Zeder which Lühe did not accept, but on the other hand continued to use the generic name Monostoma instead of *Cyclocoelum* Brandes.

Stossich in 1902 on the suggestion of Brandes divided the group Monostomata into two sub-families, Notocotylinæ and Cyclocoelinae. In the latter he included four genera, *Cyclocoelum* Brandes, *Hæmatotrephus* Stossich, *Ophthalmophagus* Stossich and *Typhlocoelum* Stossich. Kossack in 1911 raised the sub-family Cyclocoelinae to the rank of the family Cyclocoelidae in which he included the following genera. *Cyclocoelum* Brandes, *Allopyge* Johnston, *Hæmatotrephus* Stoss, *Hyptiasmus* Koss, *Ophthalmophagus* Stoss, *Typhlocoelum* Stoss, *Spaniometra* Koss, and *Bothriogaster* Fuhrm. Skrjabin, 1913, created a new genus *Tracheophilus* which he placed in the family Cyclocoelidae and also described the anatomy of *C. orientale* from *Glottis nebularius*.

Harrah classified the Monostomata into four families. Cyclocoelidae Kossack, 1911, Notocotylidae Lühe, 1909, Collyriididae Ward, 1917, and Heronimidæ Ward, 1917, and divided the family Cyclocoelidae into three sub-families. Cyclocoelinae Stoss, 1902, Typhlocoelinae Harrah, 1922, and Ophthalmophaginae Harrah, 1922. In the sub-family Cyclocoelinae he included three genera: *Cyclocoelum*, *Hæmatotrephus* and *Hyptiasmus*; in the sub-family Typhlocoelinae, two genera. *Typhlocoelum* and *Tracheophilus*, and in the sub-family Ophthalmophaginae three genera: *Ophthalmophagus*, *Bothriogaster* and *Spaniometra*.

Witenberg in his first memoir published in 1923 created two genera *Problemogenus* and *Promptenovum*, a sub-genus *Mediopharyngeum* and a species *Cyclocoelum* (*Antepharyngeum*) *goliath*, all belonging to the sub-family Cyclocoelinae. But in a subsequent paper in 1926 in which he included his previous work he dropped the above-mentioned genera and the sub-genus and accepted the two sub-families Cyclocoelinae Stoss, and Typhlocoelinae Harrah, dropping the third sub-family, *ie*, Ophthalmophaginae Harrah, 1921. He also divided the sub-family Cyclocoelinae into seven tribes, *ie*, *Wardiana*, *Haematrotrephea*, *Cyclocoela*, *Hyptiasmen*, *Ophthalmophaga*, *Bothriogasterea* and *Contracoela*, each consisting of five genera.

This lengthy classification was criticised in 1926 by Joyeux and Baer who did not consider the characters distinguishing the different genera and tribes to be of even specific importance. They did not accept also the sub-families Cyclocoelinae and Typhlocoelinae saying that the presence or absence of outgrowths in the intestinal caeca at the most is of generic importance. According to Joyeux and Baer the family Cyclocoelidae contains only three genera, namely, *Cyclocoelum* Brandes, 1892, *Typhlocoelum* Stoss, 1902, and *Spaniomatra* Kossack, 1911. The other genera included in this family by the previous workers, the joint authors have reduced to the rank of species, giving a list of synonyms, dropping some new names used for the old ones. Morishita in 1930 agrees in principle with the classification given by Joyeux and Baer, considering it more concise and suitable for practical purposes. He included sixteen species under the genus *Cyclocoelum*. I follow Joyeux and Baer and Morishita in the classification of the family and think that the genera now included in it are based on constant and deep morphological characters. As a large number of old genera have been dropped or reduced to the rank of species the systematic study of the group has become clearer.

### **Diagnosis of the genus *Cyclocoelum* Brandes, 1892.**

Endoparasitic trematodes of middle to large size with elongated muscular body and smooth body-wall. Mouth opening terminal or subterminal, oral sucker rudimentary or absent, ventral sucker absent except in *C. distomatum* Morishita, 1924, and *C. vagum* Morishita, 1924. Pharynx well developed and muscular, oesophagus long and muscular; intestinal caeca simple and continuous with each other in the form of an arc near posterior end of body. Excretory bladder between posterior intestinal

arc and posterior body wall with medio-dorsal terminal pore. Genital opening median and ventral to pharynx. Cirrus sac well developed containing vesicula seminalis and ductus ejaculatorius Vitellaria laterally situated, between body wall and intestinal cæca. Genital glands intracæcal in posterior half of body forming the points of triangle or in straight line one behind the other, ovary between two testes or anterior to both Receptaculum seminis present or absent Laurer's canal absent Receptaculum seminis uterinum present or absent Uterus well developed filling intracæcal space in front of posterior testis and much convoluted in more or less regular folds, sometimes overlapping intestinal cæca Eggs numerous, without polar filament, usually containing well developed miracidia with characteristic double eyespots.

**Key to the Indian species of the genus *Cyclocoelum* described  
in this paper**

- |   |  |     |                         |
|---|--|-----|-------------------------|
| 1 | Ovary anterior to testes   | ... | <i>C. nebularium</i>    |
|   | Ovary between testes   | ..  | 2                       |
| 2 | Ovary in line with testes  | .   | .. <i>C. straightum</i> |
|   | Ovary not in line with testes  | ..  | 3                       |
| 3 | Ovary lobed ..   | ..  | .. <i>C. lobatum</i>    |
|   | Ovary compact .  | ..  | .. 4                    |
| 4 | Uterine coils not overlapping cæca                                       | ..  | ... <i>C. capellum</i>  |
|   | Uterine coils overlapping cæca   |     | 5                       |
| 5 | Uterine coils closely situated, ratio between<br>testes and ovary 5 2    |     | <i>C. allahabadi</i>    |
|   | Uterine coils well separated, ratio between testes<br>and ovary 3 2      | ..  | ... <i>C. indicum</i>   |
|   | Receptaculum seminis and receptaculum seminis<br>uterinum well developed | ..  | ... <i>C. mehris</i>    |
|   | Receptaculum seminis and receptaculum seminis<br>uterinum absent.        | ... | . <i>C. erythropis</i>  |

***Cyclocoelum nebularium*, n sp.**

A dozen specimens of this species were collected from the air sacs mostly from the abdominal ones of the common green shank—*Glottis nebularia*, near Allahabad They are medium sized, 10—13\* long and

\*All measurements are given in mm.



2—3·5 in maximum breadth which lies slightly anterior to the region of the gonads, 1 ♂, at the beginning of the posterior 1/5 part of body. From the maximum breadth the body tapers gradually to a slightly rounded anterior end, measuring 0·85 in the region of the pharynx. In the region of the gonads it is more or less straight with parallel sides ending in a broadly rounded end, where it measures 2—3·3 in breadth.

The pharynx is well developed, 0·25—0·35 long and 0·2—0·25 broad. I agree with Monticelli and Harrah in considering it as the pharynx and not the oral sucker as Braun in 1901 thought it to be. It does not show the radial, inner and outer layers of muscle fibres as are present in the sucker but on the contrary it has the typical musculature of the pharynx. The oesophagus is S-shaped, but in some specimens it is more or less straight, two to three times the length of the pharynx, roughly 0·511—0·512 long and 0·085 broad, and bifurcates 1·125—1·275 behind the anterior end. The intestinal cæca, devoid of diverticula, run parallel to the body wall in a slightly irregular course and join with each other posteriorly in an arc 0·285 in front of the anterior end. The excretory bladder lies between the intestinal arc and posterior extremity of the body with hinder ends of the vitellaria on its sides, measuring 0·56—0·85 in length and 0·085—0·185 in breadth. It opens to the exterior through a pore situated dorsally at the posterior end.

The genital glands lie in the intercæcal region enclosed by the intestinal arc and form three points of a triangle with the ovary as the apex. The two testes lie obliquely behind the ovary. The anterior testis is round, situated to the side opposite to that of the ovary, 0·5—0·6 distance behind it and measures 0·7—1·0 in diameter. It is almost equal in size to the posterior testis except in a few individuals in which the latter may appear more elongated due to pressure.

The posterior testis lies somewhat median or little shifted to the same side as the ovary, obliquely behind the anterior testis from which it is separated by the transverse vitelline duct. It is generally rounded, somewhat elongated, measuring 0·71—1·2 in greatest length and 0·51—0·93 in greatest breadth. The uterine coils do not pass behind the anterior testis, between it and the posterior testis as is usually the case in the genus. In immature specimens of hardly more than 7·0 length the testes do not measure more than 0·45 in diameter. The vasa efferentia arise from the anterior margins of the testes near the outer side and unite cephalad and mediad to the posterior testis behind the ovary to form the long vas deferens which takes a more or less straight course to the cirrus sac in which it dilates into a more or less straight vesicula seminalis. The latter fills up

the basal  $2/3$  part of the cirrus sac and opens to the exterior at the common genital pore. The cirrus has not been observed in the protruded condition. The cirrus sac is tubular and dilated posteriorly, extending from the genital pore to the anterior end of the intestinal bifurcation and measuring 0.8–1.0 in length and 0.2–0.3 in maximum breadth. The anterior narrower  $1/3$  part of the sac in some specimens is bent in a crescent-shaped manner while in others it is more or less straight.

The ovarian complex occupies a position anterior to both the testes, a rare position for the genus, which was previously considered as characteristic of the genus *Hamatotrophus*. The ovary, almost rounded with entire margin, lies 1.8 in front of the hinder end, either to the right or left side of body, alternating with the anterior testis. It is smaller than the testes, measuring 0.31–0.41 in diameter,  $\frac{1}{2}$  e,  $\frac{4}{7}$  of the anterior and  $\frac{4}{9}$  of the posterior testis in diameter. The short oviduct arises from the posterior margin of the ovary and runs backwards to enter the shell gland complex, which is almost rounded with fringed margins, measuring 0.3 in diameter. The receptaculum seminis is situated inside the ovary near the median line, measuring 0.15–0.35 in length and 0.05–0.11 in breadth. Morishita in his paper in 1924 calls this organ as the ootype because of the absence of sperms in it. Though the sac is devoid of sperms I do not agree with Morishita, because the ootype, as is well known, is a slightly dilated part of the oviduct surrounded by the shell glands. The receptaculum seminis opens into the oviduct immediately before it becomes surrounded by the shell glands on the side opposite to that on which the common vitelline duct enters it. The Laurer's canal is absent. The uterus at its commencement is swollen to form the receptaculum seminis uterinum which lies in the form of a loop between the anterior testis and the ovary, and is always filled with sperms. The uterine convolutions in the form of well developed loops are directed with their outer ends almost posteriad up to the intestinal bifurcation. In front of the latter the uterus runs in more or less straight course, opening externally at the genital pore.

The vitellaria are laterally situated, confined to the extreme edges of the body and are composed of small follicles extending anteriorly to the middle of the intestinal bifurcation and posteriorly to the lateral walls of the excretory bladder. In one specimen they are joined with each other posteriorly forming an arc just in front of the excretory bladder; while in other specimens though they are not joined at the posterior end they reach quite close to each other. Anteriorly the vitellaria do not end at the same level; the gland situated to the same

side as the ovary extends more anteriorly. The transverse vitelline ducts arise at about  $1/8$ th body length from the posterior end. The one situated to the ovarian side is shorter, arises more anteriorly than its fellow and runs in a more or less straight course close in front of the posterior testis, sometimes overlapping its anterior margin. The yolk reservoir lies median close in front of the posterior testis and enters the shell gland mass by a short common vitelline duct. The longitudinal vitelline ducts lie surrounded by the vitelline follicles, laterally or dorsally to the intestinal cæca.

The eggs are large, thick-shelled without operculum and show miracidia with characteristic double eye spots, measuring  $0.12 \times 0.087$  in size. The unripe eggs without miracidia measure  $0.101 \times 0.085$  in size.

*Remarks .—*

Before 1926 all the species having the ovary in front of testes were included in the genus *Hamatotrephus*. Joyeux and Baer in 1926 and Morishita in 1930 dropped the latter genus and included all the species belonging to it in the genus *Cyclocoelum*. The new species resembles *C. brazilianum* Stoss and *C. tringa* Brandes, in the testes being obliquely situated behind the ovary, but it differs from them in the size of the body which is almost twice as large as that of *C. tringa*, in the larger size of the pharynx, absence of the oral sucker and the greater ratio between the size of the ovary and testes. It differs further from *C. brazilianum* in having the testes of equal size and the posterior extent of the cirrus sac, which reaches quite close to the anterior wall of the intestinal bifurcation. It differs from *C. wilsoni*, *C. triangularium* and *C. tazorchis*, in which too the ovary lies anterior, in the oblique position of the testes. *C. nebularium*, n. sp., however, occupies an intermediate position between *C. brazilianum* and *C. tringa* on the one hand and *C. wilsoni*, *C. tazorchis* and *C. triangularium* on the other, resembling the first two in the oblique position of the testes and the last three in the equal size of the latter.

***Cyclocoelum straightum*, n. sp.**

Only one specimen of this species was obtained during the month of November 1932 from the abdominal air sac of *Glottis nebularia*, caught from the fields of Phulpore near Allahabad. Subsequently about hundred specimens of different genera of the Scolopersidae were examined but none was found infected with this species. Body long, dorso-ventrally flattened, in pressed specimens 25 long and 4.3 in maximum breadth in the region of anterior testis, i.e., at about  $1/6$ th body length from posterior end; tapering in front and behind anterior testis, 2.5 in breadth in

region of posterior testis and 1.2 in that of pharynx; anterior end bluntly pointed, posterior end broadly rounded, body wall devoid of spines

Oral sucker very feebly developed, barely visible, measuring 0.15 in length and 0.11 in breadth, i.e.,  $\frac{1}{3}$  of pharynx in size. Ventral sucker absent

Mouth subterminal leading by a funnel shaped cavity into pharynx of 0.344 length and 0.425 breadth, situated 0.45 from extreme anterior end, oesophagus S-shaped or straight, 1.0 in length and 0.11 in breadth; intestinal bifurcation 1.88 distance from anterior end, caeca without diverticula, situated laterally parallel to the body wall and uniting behind to form an arc at 0.3 distance in front of hinder end. Excretory pore dorsal and terminal, excretory bladder horizontally situated between intestinal arc and posterior end of body with terminal ends of vitellaria on its sides and measuring 0.68 in length and 0.11 in breadth

Gonads in posterior one sixth part of body, with ovary between testes and in line with them and not forming points of a triangle. Both the testes are separated from one another by ovary, shell gland complex and three uterine coils, anterior testis to right side, 0.5 from right wall, 0.26 from right caecum, 0.52 in front of ovary, 3.5 in front of posterior end and 1.7 in front of posterior testis. It is transversely elongated and pear shaped with entire margin, measuring 1.05 in length and 0.68 in maximum breadth, posterior testis situated mesially 0.75 in front of posterior end, 0.25 in front of intestinal arc and 0.5 behind ovary, separated from the latter by transverse vitelline ducts, shell gland mass and uterine coils and measuring 1.25 in length and 0.99 in maximum breadth. Vasa efferentia arise from anterior ends of testes, vas deferens traced from anterior one-third of body to cirrus sac, straight bulbous vesicula seminalis filling posterior two-third part of cirrus sac, ductus ejaculatorius narrow and tubular in anterior one-third part or neck of cirrus sac; pars prostatica, prostate gland cells and cirrus not observed. Cirrus sac curved and nearly flask-shaped with an anterior transversely lying tubular one-third part, the neck, of 0.28 length and 0.06 breadth and posterior two-thirds dilated part of 0.55 length and 0.27 breadth reaching near intestinal bifurcation, ending 0.15 distance in front of it.

Ovary almost median or a little to right side, 0.75 from anterior testis and 0.5 from posterior testis, nearly spherical with entire margins and slightly pressed posteriorly by receptaculum seminis, 0.45 in length and 0.41 in breadth, i.e., almost one-third of posterior testis; oviduct arises from posterior lateral corner of ovary; shell gland mass, of more or less oval shape with fringed margins, median, to left side of ovary, 0.68 in

length and 0.58 in breadth,  $\pm$  e, about one and a half size of the latter, receptaculum seminis, 0.35 long and 0.5 broad, situated immediately behind ovary, slightly pressed with its long axis to the latter. The ootype has a little broader calibre than the oviduct and runs a straight course surrounded by the shell gland mass. Laurer's canal absent as usual in the family. Receptaculum seminis uterinum large filled with sperms and a few ova, approximately 1.0 long and 0.25 broad, situated horizontally to left side between left caecum and shell gland mass, uterine convolutions filling almost the whole body in the form of slightly separated loops with ends directed outwards towards the caeca, extending forward up to intestinal bifurcation, beyond the latter uterus more or less straight.

Vitellaria extend from middle of intestinal bifurcation to excretory bladder, transverse vitelline ducts arise from posterior  $\frac{1}{8}$  length of vitellaria but not at the same level, the right one at higher level than left, the right duct runs transversely almost straight for 1.45 distance before it joins its fellow behind shell gland mass, left transverse duct which arises 1.3 in front of posterior end of body runs straight for 0.5 and then turns upwards for a distance of 1.0 before it joins its fellow to form the small rather inconspicuous yolk reservoir which immediately opens in shell gland mass.

Ova thick-shelled, non-operculate with fully developed miracidia; unripe ova yellowish brown, 0.116 in length and 0.06 in breadth, ripe ova dark brown, 0.136 in length and 0.068 in breadth.

### **Cyclocoelum capellum, n. sp.**

About a dozen specimens of this species were obtained mostly from the cervical air sacs of the common fan tail snipes—*Capella gallinago* near Allahabad, India. The infection seems to be seasonal and rare as the parasites were obtained before September and after November. The number of worms found in a single host was never more than three. Body 17–25 in length and 3.5–4.6 in maximum breadth at the beginning of the posterior one-fourth part of body, breadth 3 in region of posterior testis, 1.1–1.2 in region of pharynx. Oral sucker subterminal and rudimentary, 0.08 in length and 0.04 in breadth; pharynx 0.275 in diameter, almost rounded at 0.085 distance behind anterior end, oesophagus S-shaped or straight, approximately 0.3–0.5 in length and 0.1 in breadth; intestinal bifurcation 0.65 behind anterior end; caeca without diverticula joining each other posteriorly to form an arc at 0.2 in front of posterior end. Excretory bladder of 0.35–1.1 breadth and 0.06 length horizontally parallel to posterior wall of intestinal arc; excretory pore dorsal and terminal.

Gonads in posterior fifth of body forming three points of a triangle, anterior and posterior testes separated from one another by five pairs of uterine coils; anterior testis at a distance of 45 from posterior end, 23 from posterior testis and 175 from ovary, situated to right side near intestinal caecum, slightly smaller than posterior testis, measuring 0.8 in length and 0.6—0.8 in breadth, posterior testis median, much lobed, close in front of intestinal arc, 12 in front of posterior end and 0.9 behind ovary, separated from the latter by vitelline ducts, shell gland mass and receptaculum seminis uterinum measuring 11 in length and 0.7—0.88 in breadth. Vasa efferentia join at about middle of body to form vas deferens which runs in an irregular course; vesicula seminalis followed by a thin narrow ejaculatory duct enclosed in cirrus sac opens into genital pore at posterior margin of pharynx. Cirrus sac flask-shaped with basal portion hardly reaching intestinal bifurcation, neck of cirrus sac 0.2 long and 0.015 broad and saccular portion 0.4 long and 0.17 broad. Ovary to the left side 0.8 from left body wall and 0.2 from left caecum, more or less spherical with entire margins, 0.37—0.55 in length and 0.37—0.5 in breadth, shell gland mass immediately behind ovary pressed against it at its posterior end, rounded with fringed margins and 0.45 in diameter, receptaculum seminalis somewhat pear-shaped, situated to inner side of ovary, 0.3—0.4 in length and 0.15—0.2 in breadth, receptaculum seminis uterinum filled with sperms and a few ova, measuring 0.7 in length and 0.25 in breadth, uterus turning upwards and outwards in front of posterior testis and thrown into double loops throughout its anterior course, confined to intercaecal region never overlapping caeca, metraterm straight from posterior end of intestinal bifurcation to genital pore. Vitellaria laterally situated parallel to body wall, between it and intestinal caeca ending anteriorly not at the same level, the one situated to ovarian side extending a little more forwards upto region of cirrus sac, posteriorly they terminate 0.25 in front of lateral ends of excretory bladder; right transverse vitelline duct arises at 2.3 from posterior end and runs almost straight for 2.0, left transverse vitelline duct arises at a lower level i.e., 1.70 from posterior end and is much shorter running straight for 0.6; yolk reservoir of 0.15 length opens dorsally in shell gland mass near the origin of uterus. Ova in posterior one-fourth part of body brownish yellow, 0.12 in length and 0.064 in breadth, while in anterior 3/4 part of body ripe dark brown and having fully developed miracidia,  $0.13 \times 0.068$  in size.

**Remarks:—**

This species differs from all the species in the following combination of characters: (1) uterus confined to intercaecal region, (2) peculiar

shape of cirrus sac with its narrow neck, (3) in the size ratio between oral sucker and pharynx, (4) large size of yolk reservoir, (5) size of gonads, pharynx, oesophagus, cirrus sac and ova. It differs from *C. allahabadi* in the uterine coils being confined to the intercæcal zone, in which it resembles *C. mutabile* Zeder. *C. cuneatum* Harrah and *C. leidy* Harrah and *C. toratsugumi* Morishita. But it differs from them in the lobed character of its posterior testis, ratio of oral sucker to pharynx, relative size of the gonads and the testes being widely separated.

### **Cyclocoelum allahabadi, n. sp.**

Only five specimens were obtained mostly from the thoracic air sacs of the common red shank snipes—*Tringa erythropus*—near Allahabad, India. The infection is very rare as out of thirty snipes examined only four were found infected. The number of parasites in a host is generally one and never more than two. The infection is found only in the rainy season and early part of winter. Size 17 in length, 2.5–3 in maximum breadth at beginning of posterior fourth part, breadth in the region of posterior testis 1.3–1.7 and in that of pharynx 0.68–0.85, posterior end rounded, anterior end bluntly pointed, subterminal mouth surrounded by a more or less laterally flattened oral sucker of  $0.07 \times 0.2$  size, situated 0.05 behind anterior end; pharynx spherical of 0.28 diameter, oesophagus S-shaped, 0.51 long and 0.085 broad, intestinal bifurcation at 0.85 distance behind anterior end, cæca lateral, passing into each other at hinder end to form an arc at 0.25 in front of posterior end.

Gonads in posterior 1/6th part of body, ovary in between and alternating with testes, anterior testis close inside and touching right cæcum at 1.7 from posterior end, 1.1 from hinder testis and 0.8 from ovary, more or less spherical, measuring 0.8–0.85 in length, posterior testis 0.6–0.7 behind ovary from which it is separated by transverse vitelline ducts, spherical, vas deferens from middle of body to cirrus sac; straight bulbous vesicula seminalis followed by ductus ejaculatorius, genital pore ventral at posterior end of pharynx; cirrus sac club-shaped consisting of a narrow duct like anterior part of 0.2 length and 0.07 breadth and a posterior dilated part of 0.4 length and 0.18 breadth extending upto middle of intestinal bifurcation.

Ovary situated to the side opposite to that of anterior testis, 0.35 inside corresponding cæcum and 1.3 inside corresponding lateral body wall, 0.4 in front of posterior testis and 0.8 behind anterior testis, with entire margins and  $0.3-0.35 \times 0.2-0.25$  in size; receptaculum seminis

well developed, inside ovary near median line and  $0.25 \times 0.14$  in size; shell gland mass,  $0.34$  in diameter, with fringed margins, posterior to left side of ovary and not exactly between it and posterior testis as is usual in the genus, uterus runs downwards between ovary and posterior testis and then turns upwards to continue its forward course; convolutions arranged transversely in close contact with one another filling the body between intestinal bifurcation and posterior testis; metraterm straight from intestinal bifurcation to genital pore

Vitellaria lateral, restricted to extreme edges throughout body length, extending over cæca at places and reaching uterine coils, not extending to the same level anteriorly, right transverse vitelline duct arises  $0.45$  behind anterior testis and runs downwards in a more or less straight course for  $0.7$  distance till it reaches anterior margin of posterior testis and turns slightly upwards for  $0.4-0.5$  distance to join left vitelline duct which arises  $1.4$  in front of posterior end, common vitelline duct of  $0.2$  length enters shell gland mass near junction of receptaculum seminis with it. Ova thin shelled and operculate, immature ova yellowish brown,  $0.118 \times 0.08$  in size, mature ova dark brown,  $0.119 \times 0.08$  in size.

*Remarks.*—

This species differs from *C. capellum*, n. sp. in the uterine coils extending over intestinal cæca, in *C. capellum* the uterus is restricted to intercæcal zone. The general topography of the gonads is of Mutabile type and in this respect it resembles *C. elongatum* Harrah, *C. obliquum* Harrah, *C. microstomum* Creplin, *C. obscurum* Leidy, *C. problematicum* Stoss., *C. ovapunctatum* Stoss., *C. vicarium* Kossack, *C. orientalis* Skrjabin, *C. leidy* Harrah, *C. pseudomicrostomum* Harrah, *C. cuneatum* Harrah, *C. macrorchis* Harrah and *C. mutabile* Zeder. From all the above mentioned species it differs in the size of the body and size ratio of gonads. It differs from *C. mutabile*, *C. cuneatum* and *C. leidy* in the uterus overlapping cæca. It resembles closely *C. microstomum*, *C. pseudomicrostomum*, *C. obscurum*, and *C. vicarium* in having testes of equal size. It, however, differs from the last two in having pharynx larger than oral sucker and from the first two in position of genital pore, in the size ratio between testes and ovary, in body size and size of eggs.

*Cyclocoelum indicum*, n. sp.

Only two specimens of this species along with a few specimens of *C. nebularium*, n. sp. were obtained from the body cavity of one common green shank snipe—*Glottis nebularia*—in November, 1932. Length  $20-27$



and maximum breadth 4-4.5 at the beginning of posterior fourth of body *i.e.*, at a distance of 2.5 in front of anterior testis. From this point forward the body tapers gradually to a small rounded anterior end; posterior end bluntly rounded, 2.5-3 in breadth across posterior testis. Mouth subterminal, surrounded by a poorly developed rudimentary oral sucker of 0.1 diameter, situated at 0.1 from anterior end, pharynx 0.25 from anterior end almost three times the size of oral sucker, 0.28 in diameter; straight oesophagus 0.58-0.7 long and 0.085-0.13 broad; intestinal bifurcation 1.2 distance from anterior end, caeca simple, lateral near body wall, uniting with each other at 0.2 distance in front of posterior end to form an arc. Excretory bladder behind and parallel to posterior wall of intestinal arc, 0.55 in breadth, excretory pore dorsal at hinder end.

Testes as usual in posterior region of body confined to intercæcal zone; posterior testis not large enough to fill intestinal arc, more or less spherical with irregular margins, 0.85-0.93 in diameter, situated 0.85 in front of hinder end, 0.15 in front of posterior intestinal arc and 1.0 behind ovary, anterior testis 1.8 in front of ovary and 2.2 in front of posterior testis separated from the latter by four or five uterine coils, to the left side touching intestinal caecum and spherical with regular margins, almost equal to posterior testis in size measuring 0.85 in diameter, vas deferens runs in anterior half of body, straight vesicula seminalis, ejaculatory duct in narrow neck of cirrus sac, genital pore in mid-ventral line behind pharynx; cirrus sac club-shaped with anterior one-third part narrow and tubular of 0.25 length and 0.06 breadth and posterior two thirds dilated saccular part of 0.5 length and 0.2 breadth.

Ovary between testes and alternating with them forming three points of a triangle at 1.0 from anterior testis, 0.4 from right caecum and 0.7 from right body wall, spherical with entire margins, 0.5-0.6 in diameter, and separated from posterior testis only by shell gland mass and transverse vitelline duct and uterine coils, shell gland mass about the size of ovary and pressed against the right wall of the latter, spherical with fringed margins and 0.5 in diameter; receptaculum seminis elongated with irregular margins inside ovary and  $0.34 \times 0.17$  in size. Vitellaria dense irregular masses of follicles confined to lateral margins of body extending right from lateral ends of excretory bladder to middle of oesophagus but not ending at the same level anteriorly, right extending more forwards than the left; transverse vitelline ducts arise 2.6 in front of posterior end, *i.e.*, from posterior fifth of vitellaria; right transverse duct soon after its origin about level of posterior wall of shell gland mass bends and runs

closely outside and behind receptaculum seminis uterinum for 1'0 before it joins the left duct; receptaculum seminis uterinum of  $0'5 \times 1'0$  size situated horizontally behind shell gland mass, between it and right transverse vitelline duct, uterine coils widely separated extending over caeca and reaching body wall, metraterm straight from intestinal bifurcation to genital pore, immature ova of yellowish brown colour and  $0'102 \times 0'06$  size filling first third part of uterus, mature ova, thin shelled with fully developed miracidia, measure  $0'12 \times 0'068$  in size

*Remarks —*

*C. indicum*, n sp, has the same topography of genital organs as characterises the Mutabile group. Among the so far known species of this group it resembles only the well-known species *C. microstomum* Creplin and *C. pseudomicrostomum* Harrah, but it differs from them in size of body, ratio between pharynx and oral sucker, size of ova and position of genital pore. It is distinguished from *C. allahabadi*, on account of greater breadth of body, size of ova, widely separated uterine coils and presence of receptaculum seminis uterinum. It differs from *C. erythropis*, n sp, in size of body, large size of ovary and ova, presence of receptaculum seminis, shape and size of cirrus sac, position of genital pore and peculiar arrangement of uterine convolutions.

***Cyclocoelum erythropis*, n. sp.**

A large number of specimens were obtained from the air sacs of the common dusky red shank—*Tringa erythropus* near Allahabad. It is one of the commonest species of the genus met with at Allahabad from October to January. The largest number of parasites obtained from a single host was ten. Length 7.5—17 and maximum breadth 1.7—2.3 in the region of anterior testis, i.e., at the beginning of hinder fifth body; posterior end rounded and 1.3—1.7 in width; anterior end bluntly pointed, measuring 0.5—0.9 in breadth in the region of pharynx. Oral sucker, 0.15 in length and 0.1 in breadth, feebly developed and subterminally situated, 0.1 behind anterior end. Pharynx 0.15—0.25 in diameter; oesophagus more or less straight, 0.5—0.6 in length and 0.085 in breadth, intestinal bifurcation 1.0 behind anterior end; caeca simple, uniformly wide, 0.15 in breadth, not so wide as in other species; intestinal arc 0.15 in front of hinder end. Excretory bladder horizontally parallel to posterior wall of intestinal arc and longer than that in other species, measuring  $0.12—0.15 \times 0.19—0.34$  in size, excretory pore median dorsally situated at hinder end.

Gonads in posterior one-fifth part of body; posterior testis not filling entire intestinal arc, median, 0.2 in front of the latter, spherical with regular margins and 0.5—0.68 in diameter, anterior testis 1.2—1.5 in front of posterior testis and separated from it by four or five uterine coils, more or less spherical with entire margins and almost equal to posterior testis in size, measuring 0.5—0.68 in diameter, vas deferens traced only in anterior fourth body, vesicula seminalis straight and inside cirrus sac, genital pore ventral just behind pharynx, cirrus sac somewhat club-shaped with anterior fourth part of 0.085  $12 \times 0.07$  size narrow and tubular, and the rest of 0.255—0.36  $\times$  0.13—0.18 size dilated and reaching middle of intestinal bifurcation. Ovary very small, spherical with entire margins, 0.19—0.29 in diameter, near right side 0.4—0.6 inside corresponding body wall, in between but opposite to the testes, 1.3 behind anterior testis and 0.5—0.7 in front of posterior testis from which it is separated only by shell gland mass and a single coil of uterus; receptaculum seminis uterinum and Laurer's canal absent, shell gland mass spherical; uterus runs forwards in closely situated coils extending laterally over caeca and reaching vitellaria in posterior three-fourths of body, in front of which it runs almost straight to intestinal bifurcation, metraterm short.

Vitellaria laterally pressed against body wall from intestinal bifurcation to lateral margins of excretory bladder, extending more forward on the side towards ovary; transverse vitelline ducts arise between shell gland mass and posterior testis, the one towards ovary much shorter, one-third of the other in length, yolk reservoir prominent, of 0.31 length.

Thin shelled ova in first one-fifth part of uterus, yellowish brown and without miracidia, 0.1  $\times$  0.08 in size.

*Remarks:—*

This species also belongs to Mutabile group of Morishita. In having testes of nearly equal size it resembles *C. microstomum*, *C. pseudomicrostomum*, *C. macrorchis*, *C. viscarum*, *C. allahabadi*, n. sp., and *C. capellum*, n. sp., but differs from *C. macrorchis* and *C. viscarum* in having pharynx larger than oral sucker. It differs from the others:—(1) in the absence of receptaculum seminis, and receptaculum seminis uterinum, (2) small size of ovary and ova, (3) size of body, (4) characteristic arrangement of uterine coils which uniformly cover anterior half of intestinal caeca, (5) shape and extent of cirrus sac and (6) narrow breadth of intestinal caeca.

***Cyclocoelum mehrii*, n. sp**

This is one of the commonest species met with in the common fan tail snipe—*Capella gallinago gallinago*. The infection does not appear to

be seasonal though it is highest in the months of November and December when the greatest number of parasites obtained from a single host was twelve and the rate of infection more than sixty per cent. In other months of the year the maximum number of parasites obtained was four and the rate of infection not more than thirty per cent. Length 18—28 and maximum breadth 3·4—5 in front of anterior testis, *s. a.*, at the beginning of posterior 1/6 part of body; breadth in region of posterior testis 2·5—3·5 and that of pharynx 1·1—1·2, anteriorly and posteriorly the body narrows down till it ends into rounded ends; subterminal oral sucker very rudimentary, visible only in sections, 0·085—0·1 in diameter, *s. s.*, roughly one-third of pharynx, pharynx muscular, spherical, 0·27 in diameter, 0·25 behind anterior end, oesophagus S-shaped, roughly 0·6—0·8 in length and 0·1 in breadth, intestinal bifurcation 0·7—0·9 behind anterior end, intestinal arc 0·4 in front of posterior end. Excretory bladder horizontally parallel to intestinal arc, 0·68—0·85 in length and 0·18—0·25 in breadth, excretory pore in mid-dorsal line at hinder end.

Gonads in posterior one-fifth part of body, posterior testis 0·15 in front of posterior intestinal arc, spherical, entire and 0·9—1·3 in diameter; anterior testis more or less spherical, 0·85 × 0·7—0·1 in size, lateral, inside and touching one of the caeca, 0·3—0·5 from the corresponding lateral body wall and 2·5—3·3 in front of posterior testis from which it is separated by four to five uterine coils; cirrus sac retort-shaped, extending behind anterior wall of intestinal bifurcation; vesicula seminalis of 0·42 × 0·18 size, ductus ejaculatorius of 0·21 length and 0·07 breadth; genital pore ventral to middle of pharynx. Ovary between testes towards the side opposite to anterior testis, at 0·75 distance from corresponding lateral body wall, 2—2·8 behind anterior testis, 1—1·5 in front of posterior testis and separated from the latter by shell gland mass, transverse vitelline ducts, large receptaculum seminis uterinum and a coil of uterus, spherical, entire and 0·4—0·6 in diameter; shell gland mass more or less spherical with fringed margins, 0·4—0·68 × 0·4—0·6 in size, close behind ovary; receptaculum seminis small, pear-shaped, inside ovary, 0·35—0·42 × 0·17—0·22 in size, opening by a narrow duct into oviduct before entrance of the latter into shell gland mass.

Vitellaria dense and confined to extreme edges of body overlapping caeca, extending from middle of intestinal bifurcation to lateral ends of excretory bladder, transverse vitelline ducts arise at different levels, one towards ovary at a higher level, *s. a.*, 0·2 in front of posterior end, other 0·12 in front of posterior end; yolk reservoir short, situated in the loop formed by receptaculum seminis uterinum and opens by a fairly

large, 0.7 long common vitelline duct into shell gland mass on its inner side before opening of receptaculum seminis and origin of uterus, receptaculum seminis uterinum runs transversely upto anterior margin of posterior testis and then turns forwards to form a loop which lies between and in the same line with posterior testis and ovary, uterine coils well separated from one another, overlapping caeca at places and extending forwards to intestinal bifurcation filling the body more or less completely, metraterm straight, from intestinal bifurcation to genital pore; immature ova in first third part of uterus  $0.115 \times 0.058$  in size, mature ova thin shelled with fully developed miracidia, dark brown,  $0.12 \times 0.068$  in size.

*Remarks:—*

*C. mehru* has the topography of the *Mutable* type, i.e., the gonads form three points of a triangle with ovary in between testes. In unequal size of the testes and lateral extent of uterine coils it resembles *C. problematicum* but differs from the latter in size of body, oral sucker being rudimentary and much smaller than pharynx and in the ratio of the testes and ovary, i.e., 2 : 1 in *C. mehru* and 3 : 1 in *C. problematicum*. It is the largest species known in the genus measuring 28 in length and is further distinguished by the large size of the gonads, ova, receptaculum seminis uterinum and pharynx. It differs from *C. macrorchis* and *C. vicarium* in having unequal testes, from *C. mutabile* and *C. leidy* in the uterine coils passing over intestinal caeca and from *C. obscurum* and *C. ovupunctatum* in having pharynx much larger than the oral sucker.

I dedicate this species to Dr. H R Mehra, under whom I had the pleasure of carrying on this work.

***Cyclocoelum lobatum*, n. sp.**

Only one specimen of this parasite was obtained from the thoracic air sacs of each of the two common snipes, green shank—*Gallinago nebulosa* examined. Size moderate, length 13 and maximum breadth 2.4 slightly in front of anterior testis, i.e., at the beginning of posterior fourth of body; posterior end bluntly rounded, 2.0 wide in the region of posterior testis; anterior end rounded 0.85 in width in the region of pharynx. Oral sucker not seen in toto mount; pharynx muscular, spherical of 0.27 in diameter; straight oesophagus of 0.68 length and 0.1 width; intestinal bifurcation 0.8 behind anterior end; intestinal arc 0.45 in front of posterior end. Excretory bladder comparatively small but broad between posterior end and intestinal arc, 0.35 in length and 0.17 in width with terminal ends of

vitellaria on the sides, excretory pore median and dorso-terminal. Gonads in posterior one-fourth of body, ovary between testes and on the side opposite to that of anterior testis, posterior testis median, almost spherical entire and  $0.6-0.75$  in length and  $0.55-0.7$  in breadth; anterior testis slightly elongated and equal in size to posterior testis, inside and touching the corresponding intestinal caecum,  $1.4-1.5$  in front of posterior testis from which it is separated by a compact mass of uterine coils; vesicula seminalis saccular, straight in posterior two-thirds of cirrus sac. Genital pore at middle of pharynx. Cirrus sac comparatively small reaching posteriorly just behind anterior end of intestinal bifurcation, anterior one-third narrow tubular part  $0.16 \times 0.07$  in size and basal two-thirds dilated sac like  $0.33 \times 0.2$  in size.

Ovary  $0.15$  inside the corresponding caecum,  $1.2$  behind anterior testis, close in front of posterior testis, separated from the latter only by transverse vitelline ducts, lobed and  $0.4-0.5 \times 0.35-0.55$  in size, shell gland mass,  $0.3 \times 0.17$  in size, with fringed margins, receptaculum seminis inside ovary near median line,  $0.2 \times 0.15$  in size, entering by a narrow neck at anterior margin of shell gland mass close to entrance of the oviduct. Vitellaria laterally situated from posterior end of cirrus sac right up to lateral margins of excretory bladder, ending anteriorly at the same level, transverse vitelline duct of the same side as the ovary arises at a higher level, i.e., at  $1.75$  in front of posterior end; other transverse duct arises  $1.5$  in front of hinder end. The two ducts unite just behind ovary and laterally to shell gland mass to form a small rather inconspicuous common vitelline duct which enters the latter opposite to the opening of receptaculum seminis.

Uterus emerges from posterior margin of shell gland and runs upwards into a densely crowded mass of coils filled with ova up to anterior limit of hinder one-fourth of body in front of which coils become less dense and well separated, terminating near intestinal bifurcation; receptaculum seminis uterinum absent; metraterm anterior to intestinal bifurcation. Ova thin shelled and non-operculate; mature ova thin shelled with fully developed miracidia of dark brown colour,  $0.119 \times 0.068$  in size.

*Remarks :—*

The topography of the genital organs is that of the Mutabile type. It resembles *C. macrostomum*, *C. pseudomicrostomum*, *C. macrorobis*, *C. moarium* in having the testes of equal size but differs from them in having a large pharynx, in the extremely reduced condition of oral sucker and lobed form of the ovary. It differs from all the known species of the genus in the posterior extent of the uterus, uterine coils forming a compact

mass and the lobed condition of the ovary. The vitellaria in this species extend anteriorly almost to the same level in both the arms, which is rather unusual for the genus. This species is also distinguished by the absence of receptaculum seminis uterinum.

## EXPLANATION OF PLATES

Fig. 1	<i>Cyclocoelum</i>	<i>nebularium</i>
Fig. 2.	<i>C.</i>	<i>straightum</i>
Fig. 3.	<i>C.</i>	<i>capellum</i>
Fig. 4	<i>C.</i>	<i>allahabadi.</i>
Fig. 5	<i>C.</i>	<i>indicum</i>
Fig. 6	<i>C.</i>	<i>erythropis</i>
Fig. 7	<i>C.</i>	<i>mehri</i>
Fig. 8	<i>C.</i>	<i>lobatum.</i>

## LETTERING

C.P	Cirrus Pouch.
G.P	Genital Pore
I.A	Intestinal Arc
I.C.	Intestinal Cæcum.
O.	Ovary.
O.S	Oral Sucker
Oes.	Oesophagus
Ph.	Pharynx.
R.S U.	Receptaculum Seminis Uterinum
R.S	Receptaculum Seminis
S.Gl.	Shell Gland
T.	Testis.
U.	Uterus.
V.D.	Vitelline Duct.
Vit.	Vitellaria.

Table I—Showing diagnostic characters of the species of *Cyclocoelum* hav-

Species.	Size.	Pharynx	Oral sucker	Ventral sucker	Genital pore.
<i>C. vagum</i> Morishita 1930	9—10 × 3—3.5 Greatest breadth in posterior third.	Spherical, 0.29	Feebly de- veloped	Very rudi- mentary	At the centre of anterior intestinal arc
<i>C. disto- matum</i> Morishita 1930	5.5—8 × 3.9—3.5 Greatest breadth in the posteri- or fourth.	Slightly elongated 0.18 × 0.107—0.13.	Well de- veloped	Rudimentary but visible in toto mount.	At centre of intestinal arc.
<i>C. straghtum</i> , n. sp.	25×4.3 Greatest breadth in the posteri- or sixth	Broader than long 0.34 × 0.42	Feebly de- veloped	Absent.	At posterior region of pharynx.



ing the ovary between the testes and in line with them, i.e., *C. vagum* type

Oesophagus	CIRRUS SAC	Vitellaria.	Uterine coils	Ova	Host
Short coiled dorso-ventrally.	Short, tadpole like, mostly behind intestinal bifurcation	Between cirrus sac and posterior intestinal arc	Not reaching caeca.	0 067— 0 077 × 0 087— 0 048	<i>Chrysolo- phus picta</i> Japan.
S-shaped; 0 3 long	Spindle-shaped, behind intestinal bifurcation.	Between intestinal bifurcation and posterior margin of intestinal arc	Uterine ends directed somewhat posteriad, slightly overlapping caeca.	0 050— 0 060 × 0 03— 0 04	<i>Phasiannus scutillus</i> Japan
S-shaped or straight	Anterior 1/3 tubular and posterior saccular, ending just in front of intestinal bifurcation	From middle of intestinal bifurcation to excretory bladder, i.e., behind intestinal arc.	Uterine ends directed more or less posteriad extending laterally beyond caeca.	0 136 × 0 068	<i>Glottus nebularia</i> India

Table II—Showing the Measurements of the species of Cyclocoelium having ovary anterior to testes.

Species.	Size	Pharynx Size, ratio with oral sucker	Testes, ratio between posterior testis and ovary	Genital pore	Cirrus sac	Ova.	Host
<i>C. tranga</i> Brandes, 1882.	5-6 × 1.65	0.168-0.3 × 0.195-0.35; 1.2	oblique, unequal, rounded and regular, 2.1.	behind pharynx	to anterior end of intestinal bifurcation	0.13 × 0.064	<i>Helodroma ochropus</i>
<i>C. brasiliense</i> Stoeckh, 1902	11.5-14.5 × 3.0-3.55	0.235 × 0.28, 2.3.	oblique, unequal, almost rounded, 0.625 in diameter, 3.2.	at posterior of pharynx.	ends in front of intestinal bifurcation	0.161 × 0.084	<i>Totanus floppus</i> , <i>T. melanoleucus</i> , <i>Paronella pugnax</i> and <i>Helodroma solitarius</i> , South America.
<i>C. nebulosa</i> n. sp.	10-13 × 2.0-3.5	0.25-0.35 × 0.204-0.25 oral sucker rudimentary; 4.1	oblique, equal, 0.7-1.2, 9.4.	posterior to pharynx	to anterior wall of intestinal bifurcation.	0.1-0.12 × 0.085-0.087	<i>Glotis nebulosa</i> , India.
<i>C. insorcius</i> Johnston, 1916.	8-14 × 2.28-3.5	0.265 × 0.192, 2.1.	at the same level, irregular, equal, 1.36 × 0.97; 3.1	in level with posterior end of pharynx	to middle of intestinal bifurcation	0.117-0.139 × 0.059-0.06	<i>Hamanotus leucocephalus</i> and <i>Gallinago gallinago</i> Australia.
<i>C. wislizeni</i> Harrab, 1921.	12 × 3	0.268 × 0.269; oral sucker 0.37 × 4, 3.4.	at the same level, spherical, 0.99 × 0.91 in diameter, 3.7	middle of pharynx	to middle of intestinal bifurcation	0.15 × 0.076	<i>G. wislizeni</i> ; intestine. America.
<i>C. irregularis</i> Harrab, 1921.	8 × 2	0.248 × 0.215; nearly equal.	at the same level, spherical, equal, 0.243; 6.10	at posterior end of pharynx.	to middle of intestinal bifurcation	0.132 × 0.075	<i>Tringa maculata</i> , America.

Table III.—Showing diagnostic characters of the species of *Cyclocoelum*—in which uterus is restricted to the intercæcal zone.

Species.	Size.	Pharynx; ratio with oral sucker	Testes, ratio with ovary	Cirrus sac	Genital pore.	Ova.	Host.
<i>C. mutabile</i> Zeder, 1800	16–18 x 4–4.5	Larger than oral sucker	Rounded, entire unequal, posterior larger posterior testis and ovary 2:1	Basal two-thirds slightly dilated, reaching middle of intestinal bifurcation	At anterior margin of pharynx	0.117 x 0.066	<i>Fulica atra</i>
<i>C. cuneatum</i> Harrah, 1924	10.5–12 x 2.5–3.5	Both equal, 0.19–0.22 in diameter	Anterior spherical, posterior flattened anteriorly, entire; or posterior larger than anterior, anterior testis and ovary 4:3.	Club-shaped, straight reaching anterior wall of intestinal bifurcation	At the anterior end of pharynx	0.115 x 0.066	<i>Gallinago delacata</i> , abdominal cavity
<i>C. ledgeni</i> Harrah, 1924	16–18 x 4–4.5	Oral sucker larger than pharynx, pharynx 0.281–0.3, 3.1	Spherical entire equal, 0.87–0.91 in diameter, 5:2	Straight with basal two-thirds much dilated, reaching much behind intestinal bifurcation	At middle of pharynx	0.117 x 0.066	<i>Gallinago walsoni</i> , thoracic cavity
<i>C. toralensis</i> Morishita, 1924	11–14 x 2.5–4	Oral sucker absent, pharynx 0.21–0.27 x 0.23–0.25.	Spherical or elliptical, entire, unequal posterior larger 3:2	Retort-shaped, reaching middle of intestinal bifurcation	At middle of pharynx	0.13–0.14 x 0.078–0.082	<i>Oreocercus uncinatus</i> , body cavity
<i>C. capellum</i> n. sp.	17–25 x 3.5–4.5	Oral sucker smaller than pharynx, pharynx 0.275 in diameter, 2:7	Lobed, spherical, unequal, posterior larger, anterior testis and ovary 2:1.	Flask-shaped, posterior two-thirds dilated hardly reaching intestinal bifurcation	At posterior margin of pharynx	0.13 x 0.068	<i>Capella gallinago</i> cervical air sac.

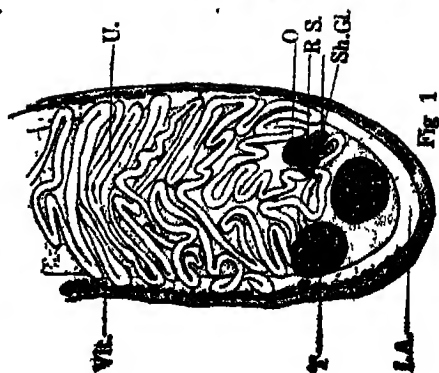
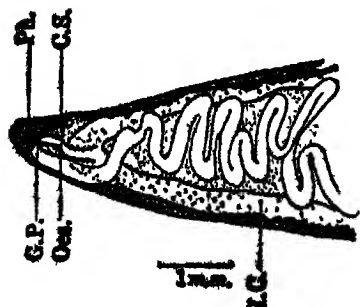
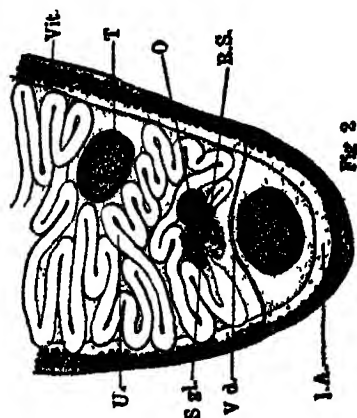
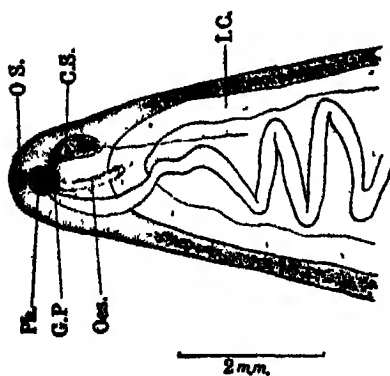
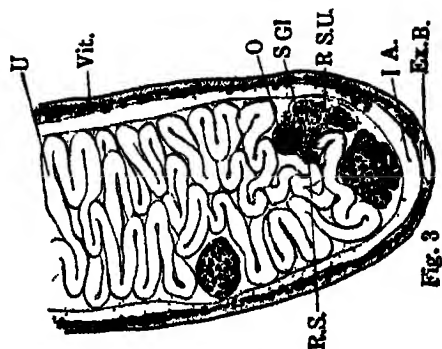
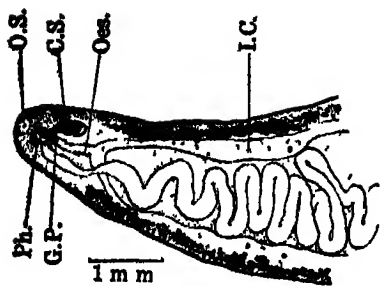
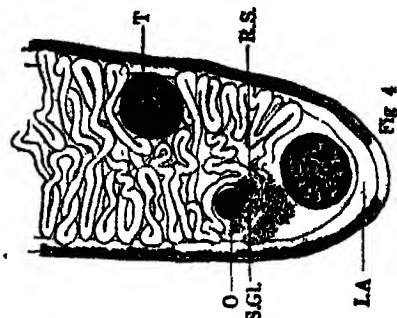
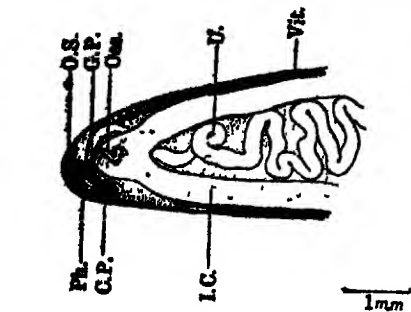
Table IV—Showing the characteristics of *Cyclocoelium* species—testes of equal size forming with ovary between them the points of a triangle; uterus not restricted to intercæcal zone

Species	Size.	Pharynx: ratio with oral sucker	Testes: ratio of testes with ovary	Cirrus sac	Genital pore	Uterine coils	Vitellaria.	Ova.
<i>C. macrostomum</i> Czeplín, 1929	13-15 × 4-5	650-700 U in diameter, 3 2	4 3	Retort-shaped; reaching posteriorly to middle of intestine. bifurcation	At middle of pharynx	Partly overlapping cæca.	Between cirrus sac and excretory bladder, partly overlapping cæca.	0 10×0 06
<i>C. pseudomerositum</i> Harrah, 1922	13-14 × 4-4 5	0 778-0 910 × 0 745- 0 844, 7 6	5 2	Extending almost to posterior wall of intestinal bifurcation	At forward end of pharynx.	Rarely overlapping cæca.	Between cirrus sac and excretory bladder, overlapping cæca and the lateral folds of uterus	0 102×0 051- 0 066
<i>C. albahabab</i> , n. sp.	17 0 × 2 5-3	0 28 in diameter; 7 5	5 2	Club-shaped, reaching behind anterior wall of intestinal bifurcation.	At posterior end of pharynx	Overlap cæca and reach vitellaria at many places.	From middle of intestinal bifurcation to excretory bladder, partly overlapping cæca.	0 12×0 08
<i>C. erythropus</i> , n. sp.	7 5-14 × 1 7-2 3	0 15-0 25 in diameter 8 7	7 3	Club-shaped reaching behind anterior wall of intestinal bifurcation	Slightly behind pharynx	Reaching interally up to vitellaria.	Between cirrus sac and excretory bladder, overlapping cæca and lateral folds of uterus	0 1×0 08
<i>C. indicum</i> , n. sp.	20-27 × 4-4 5	0 28 in diameter; 2 1	3 2	Club-shaped, reaching anterior wall of intestinal bifurcation	Behind pharynx	Extending to the body wall.	From middle of intestinal bifurcation to excretory bladder, overlapping cæca and lateral folds of uterus	0 1-0 12×0 06 -0 068

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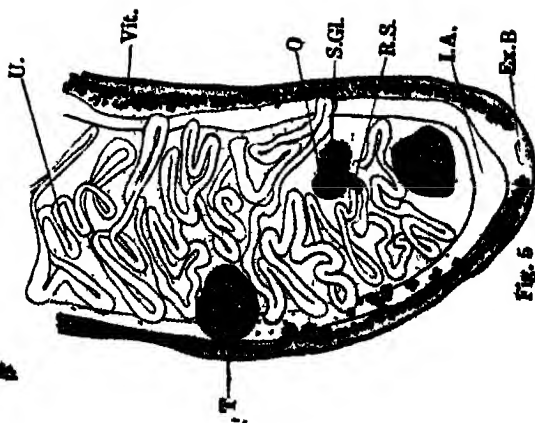
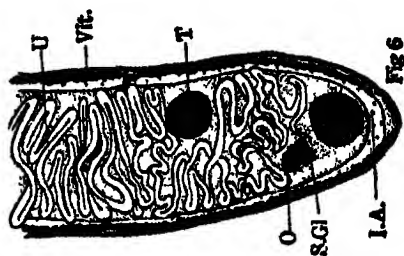
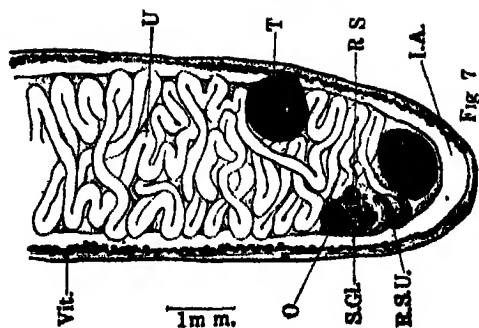
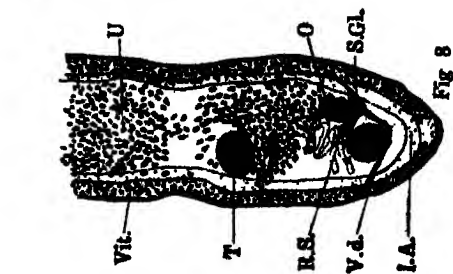
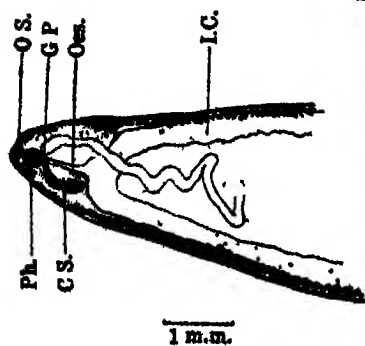
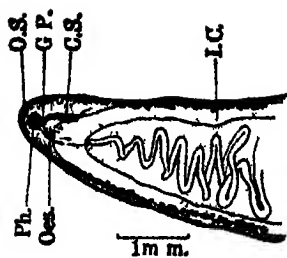
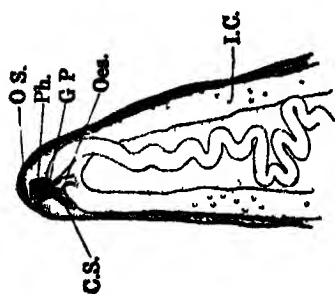
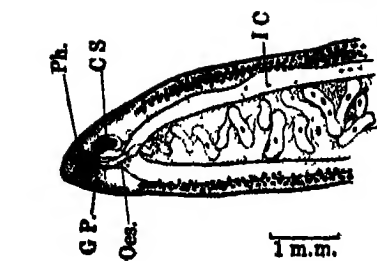


Fig 8

Fig 7

Fig 6

Fig 5



## CONTRIBUTIONS TO THE DIGENETIC TREMATODES OF THE MICROCHIROPTERA OF NORTHERN INDIA

**Part 1.**—New species of the genus *Pycnoporos* Looss with a note on  
*Anchitrema* Looss

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Communicated by Dr H R Mehra,

Received December 12, 1934

### Introduction

Hitherto the only contribution to the study of digenetic trematodes from Indian insectivorous bats is that made by Bhalerao (1926) from Burma. This paper, the first of a series dealing with the bat trematodes obtained in this part of the country, contains descriptions of two new species of distomes belonging to the sub-family Lecithodendriinae Looss (family Lecithodendridae Odhner) and to the genus *Pycnoporos*, representative of which had not been reported previously from this country. The parasites were found in the intestine of *Nyctceus dormeri*, specimens of which were collected in a village fifteen miles north of Allahabad. A short note on the genus *Anchitrema* is appended.

The work has been done under the supervision of Dr H R Mehra to whom I am deeply indebted for his valuable guidance.

### Historical account of *Pycnoporos*

In 1899 Looss established this genus with *Pycnoporos heteroporus* Dujardin (*Dist. heteroporum* Duj 1845) as the type species and described in the same paper a new species from Egypt under the name *P. acetabulatus* Dujardin. In 1845 Dujardin had placed his species in the subgenus *Brachycoelium*, but later the species was included in *Lecithodendrium* Lss. Lühe in 1899 had expressed doubts about this inclusion as also that of *Dist. macrolaimus*, a species described by von Linstow in 1894 and also put under *Lecithodendrium*. Braun in 1900 pointed out that Linstow's species

must be placed in the genus *Pycnopus*. Another new species was described by Looss from Cairo in 1907 under the name *P. inversus*. Ozaki in 1929 gave an account of *P. transversus* along with a key to the species of the genus in which he included Linstow's species as *P. macrolasmus*. Mödinger in 1930 redescribed *P. heteropus* Dujardin. Stiles and Nolan in their Key-catalogue cite Linstow's species under *Leothodendrium*.

### ***Pycnopus loossii*, n. sp.**

In the months of August and September 1934 five specimens of *Nycticejus dormeri* were examined by me. Out of these three were found infected with this species, one yielding about twenty specimens, the second only one while the third gave me five specimens. The habitat of the parasites was the small intestine.

The distomes are flat, small in size with the anterior end very mobile and measure 0.63–0.75 mm in length. In comparatively younger forms they have the same breadth in the posterior half of the body but in older ones the maximum breadth, attained in the post-testicular region in the uterine zone, is 0.28–0.36 mm. The cuticle is spinose and uni-cellular glands are present in the body anterior to the acetabulum. The oral sucker, nearly circular in outline, measures 0.037 mm in diameter and is subterminal. A spherical prepharynx, measuring 0.01 mm. in diameter, is followed by the pharynx 0.015 × 0.02 mm in dimensions. The oesophagus is a long thin tube with the intestinal bifurcation behind the anterior quarter of the body. The intestinal caeca are small elongated sacs ending a little in front of the acetabulum. The latter nearly twice as large as the oral sucker lies nearly at the middle of the body length and measures 0.074 mm in diameter. In most cases however, it is nearly spherical in outline but is fixed in different shapes on account of its highly contractile nature. The excretory pore lies at the posterior end of the body leading into the V-shape bladder, characteristic of the genus. The genital pore is median and is situated directly in front of the acetabulum.

The testes, more or less ovoid and placed behind the vitellaria slightly oblique to each other, lie laterally near the body wall. The testis of the ovarian side, measuring 0.1–0.125 × 0.075–0.087 mm. in size, is slightly larger than that on the other side which measures 0.087–0.125 × 0.0625–0.08 mm in size. The membranous cirrus-sac, more or less spherical in shape, lies immediately in front of the acetabulum with nearly the whole

of its interior occupied by a much coiled vesicula seminalis. This latter is continued anteriorly into a small pars prostatica which leads into a small ejaculatory duct opening outside at the genital pore. Between the seminal vesicle, the ducts and the wall of the sac are interspersed the prostate gland cells.

The dorsally located ovary is nearly pear-shaped in outline and lies to the left of the acetabulum, measuring  $0.08 \times 0.063$  mm in size. The oviduct arises from its hinder margin and runs posteriorly to enter the shell-gland complex, situated behind the acetabulum slightly to the left of the median line. In the shell-gland area a nearly rounded receptaculum seminis is discernible, while a little anterior to it the common yolk-reservoir opens. The Laurer's canal is present. The uterus on arising out of the shell-gland complex runs posteriorly between the testes, but behind the latter these descending coils lie mainly to one side of the body, and on reaching the posterior end the uterus turns anteriorly and forms similar coils on the other side of the body behind the testis of that side. Then this ascending limb passing forward in transverse coils in the region of the testes and dorsal to the acetabulum opens to the exterior through the genital pore. The vitellaria are situated laterally to the sides of the shell-gland area in two groups of six to eight follicles each. The group on the ovarian side lies between the ovary and the testis while that on the other is a little ahead in position, and extends anteriorly to the posterior limits of the acetabulum and posteriorly to the anterior limits of the testis of that side. The ripe eggs, elliptical in shape and yellow in colour, measure  $0.015-0.0175 \times 0.007$  mm in size.

This species resembles *P. heteroporus*, *P. acetabulatus*, and *P. transversus* in having spinose cuticle and the oral sucker being smaller than the acetabulum. It differs from *P. heteroporus* on account of the ratio between the two suckers (acetabulum in Dujardin's species is very powerful and measures 0.32 mm. in diameter while the oral sucker measures 0.065 mm), the position of the ovary, the slightly oblique position of the testes, the relative position of the vitellaria to the latter, and the size of the eggs (in *P. heteroporus* the length is 0.0819-0.021 and the breadth 0.008 and consequently the eggs are larger in this species). From *P. acetabulatus* it is to be distinguished on account of its obliquely placed testes, the posterior position of the ovary (which is situated somewhat in front of the acetabulum in the former), the posterior position of vitellaria in relation to the acetabulum (in the Egyptian species the follicles are situated to the sides of the acetabulum, the uterus intervening between them and the testes) and the smaller size of the eggs.

(which measure  $0.023 \times 0.01$  mm in size in the species described by Looss) The new species can be differentiated from *P transversus* on account of the position of the ovary and the position of the vitellaria

### ***Pycnoporus indicus* n. sp**

Five specimens of this species were obtained from the small intestine of three out of eleven bats, *Nycticephus dormeri*, examined by me in the months of March, April, August, September and December, 1934 Two of these infected bats yielded two specimens each while the third yielded only one

The distomes are thin and somewhat transparent so that a slight pressure of the cover-glass enables the internal anatomy to be elucidated under a low power of a microscope The body is flat, elongated, somewhat elliptical in shape and measures 1.43–1.59 mm. in length. Both the anterior and the posterior ends are more or less bluntly rounded but the posterior extremity appears to be slightly pointed The breadth is maximum in the middle third of the body where the gonads are situated and measures 0.42–0.442 mm. The cuticle is smooth and a large number of uni-cellular cutaneous glands is present in the body anterior to the acetabulum The oral sucker, 0.045 mm in diameter, is ventrally situated and leads into the pharynx which measures  $0.017-0.025 \times 0.22-0.03$  mm in size. The oesophagus is long, measuring 0.25 mm in length, and the intestinal bifurcation takes place in front of one-fourth of the body length from the anterior end. The intestinal caeca are short, wide sacs diverging laterally. The acetabulum, slightly smaller than the oral sucker, measures 0.035 mm in diameter and is situated in front of one-third of body length from the anterior end The ratio between the two suckers is 9.7 The excretory pore, situated at the posterior extremity of the body, leads into a small median stem which communicates with long spacious cornua of the V-shaped bladder, extending up to the posterior limits of the testes. The genital pore, in front of the acetabulum in the median line, leads into a small genital atrium

The testes, nearly spherical in shape, are situated obliquely to one another towards the lateral borders one on each side near the equator of the body The testis on the ovarian side measures  $0.156 \times 0.121$  while that on the other  $0.17 \times 0.86$  mm in size The vasa efferentia arising from the anterior end of the testes pass forwards to carry the sperms to the coiled vesicula seminalis which occupies more than two-thirds of

the inside of the pseudo-cirrus sac. The latter is a large spacious structure with its long axis parallel to body length and lies to the side of the acetabulum extending posteriorly much beyond the latter. It measures  $0.27 \times 0.086$  mm in size. The vesicula seminalis continues anteriorly into the small pars prostatica leading into a well-developed ductus ejaculatorius, which is eversible as cirrus and opens into the genital atrium by a small pore.

The ovary, oval in shape, lies to the side of the posterior part of the pseudo-cirrus sac, with its anterior limits extending to the level of the hinder border of the acetabulum and measures  $0.156 \times 0.086$  mm in size. The oviduct arising from its posterior end passes to the median line to enter the shell gland mass which is located centrally near the posterior end of the pseudo-cirrus sac. It is here that the common yolk-reservoir, the receptaculum seminis of  $0.05 \times 0.037$  mm size, and the Laurer's canal enter the mass. The uterus, after its origin from the mass of the shell gland passes posteriorly between the testes, and behind them it makes a few transverse coils before reaching near the posterior extremity of the body. It then runs forwards as the ascending uterus describing coils, longitudinal and transverse, behind the testes and then passes between them. It then passes forwards in a few coils to open into the genital atrium. The vitellaria are a group of eight to ten follicles lying on each side of the body in front of the testes. Anteriorly they extend to the level of the acetabulum. A vitelline duct from each group passes posteriorly to open into a common reservoir. The ripe eggs are oval in shape and yellow in colour, measuring  $0.017-0.02 \times 0.008-0.01$  mm in size.

In having the smooth cuticle and the acetabulum smaller than the oral sucker this new species resembles *P. macrolasmus* and *P. inversus* but it differs from them both in the ratio between the two suckers, the size, the extent and structure of the pseudo-cirrus sac-characters which are of sufficient importance to warrant the creation of a new species. Looss did not make a comparison between his species, *P. inversus*, and *P. macrolasmus* with which it is more related than with any other species of the genus. From the short account and the figure given by von Linstow his species appears to differ from *P. inversus* on account of its greater breadth, nearly circular oral sucker, slightly lateral position of the genital pore in front of the acetabulum, more posterior testes and the greater length of the ova.

The diagnosis of the genus *Pycnopus*, as given by Looss and Stiles and Nolan, is slightly modified as follows:—

Small Lecithodendriinae, cuticle densely spinose or smooth, oral sucker smaller or larger than acetabulum, pre-pharynx present or absent, pharynx followed by long oesophagus, intestinal caeca short, ending in front of acetabulum. Genital pore close in front of acetabulum. Excretory bladder V-shaped. Testes distinctly behind acetabulum in uterine zone, symmetrical or asymmetrical, pseudo-cirrus sac with a large, coiled vesicula seminalis, pars prostatica and ejaculatory duct, in the neighbourhood of acetabulum. Ovary in the vicinity of acetabulum, vitellaria pre-testicular, entirely post-caecal to right and left of acetabulum, uterus in descending and ascending coils lying mainly post-testicular, entirely filling the body behind testes, eggs  $15-23 \times 7-11 \mu$ . Parasitic in intestine of insectivorous bats.

### Key to the species of *Pycnopus*

- 1 Acetabulum larger than oral sucker
  - Acetabulum very large and powerful *P. heteroporus*
  - Acetabulum not so large
    - Ovary post-acetabular *P. transversus*
    - Ovary pre-acetabular
      - Vitellaria lateral to acetabulum, with uterus intervening between the follicles and testes *P. acetabulatus*
      - Vitellaria lateral to shell gland area, never extending anteriorly beyond posterior half of acetabulum and lying in front of testes *P. loosii*, n sp
- 2 Acetabulum smaller than oral sucker.
  - Pseudo-cirrus sac lies in front of acetabulum
    - Oral sucker circular and genital pore slightly lateral close in front of acetabulum *P. macrolasmus*.
    - Oral sucker longer than broad with its opening longitudinally placed and genital pore median just in front of acetabulum *P. inversus*.
  - Pseudo-cirrus sac extends posteriorly much beyond acetabulum *P. indicus*, n sp

### Note on *Anchitrema Loosi*

*Nyctioyus kuhli* and *N. dormeri*, the common insectivorous bats available at Allahabad, are found to harbour in its rectum an interesting

Lecithodendrid worm—*Anchitrema sanguineum*—first discovered by Sonsino in the gut of *Chamaeleo vulgaris* and described by him in 1894 as *Istomum sanguineum*. This species was fully described by Looss in 1896 who found it in the intestine of chamaeleons and in the terminal part of the intestine of bat—*Taphozous nudiventris*—in Egypt. Later Looss regarded this species as the type of a new genus, *Anchitrema*, created by him in 1899. Odhner reported the presence of this species in chamaeleons and bats—*Rhinolophus hipposciurus*—from Western Nile. Two of the fifteen bats examined by me from March to September 1934 were each found infected with only one specimen of this species.

**Description**—Body elongated, tongue-shaped, with a bluntly rounded anterior end and a pointed posterior end, measuring 3.23–5.15 mm in length and 1.1 mm in maximum breadth attained in the region of acetabulum, whitish in colour with intestinal caeca red on account of the blood of the host in them, spinose. Oral sucker subterminal, roughly circular in outline, measuring  $0.29-0.41 \times 0.32-0.46$  mm followed by spherical pharynx, 0.12 mm in diameter, oesophagus short, intestinal caeca long sinuous, dorsally situated, ending a little in front of posterior end. Acetabulum smaller than oral sucker,  $0.27-0.32 \times 0.37$  mm in size, located near union of first and second third of body length, ratio between the suckers being 5:4. A large number of uni-cellular glands in the body anterior to testes and acetabulum. Genital pore median, in front of acetabulum. Excretory pore terminal and bladder Y-shaped seen in sections. Testes oval, symmetrical, ventral and lateral to intestinal caeca with anterior ends nearly in level with posterior limits of acetabulum, and somewhat equal in size—the right one measuring  $0.34-0.58 \times 0.25$  while the left one  $0.34-0.65 \times 0.22-0.35$  mm, pseudo-cirrus-sac just in front of acetabulum with a highly coiled vesicula seminalis, opening outside through pars prostatica and ejaculatory duct, prostate gland cells well-developed. Ovary immediately post-testicular, median, dorsally situated, spherical and  $0.24-0.27$  mm in diameter, shell-gland mass just behind ovary, also median, Laurer's canal dilated and coiled receptaculum seminis absent, uterus in descending and ascending transverse coils, occupying the entire post-testicular space, lying ventral to intestinal caeca and extending laterally to vitellaria, metraterm well-developed, coiled, beginning in front of ovary, lying medianly between testes, dorsal and lateral to acetabulum; vitellaria well-developed, post-testicular, lateral to caeca near bodywall, follicles on right extending more posteriorly with  $0.54-0.78$  mm space free from posterior end while on left  $0.68-0.9$  mm.; eggs numerous, oval, measuring  $22 \times 12\mu$ .

The apparent differences between these specimens and those described by Looss relate to the posterior extent of vetellaria and egg measurements, otherwise there is a close resemblance, and I think they belong to the same species—*A. sanguineum*.

*Anchitrema* was placed under Dicrocoeliinae by Pratt in 1902 but Odhner recognised the genus as belonging to the sub-family Lecithodendriinae. Poche follows the same course as regards the systematic position of the genus. Führmann has included this genus under Pleurogenetinae.

The two important characters which make the position of the genus in the Lecithodendriinae rather questionable are the Y-shaped excretory bladder and the intestinal caeca extending post-acetabular to near the posterior end. In this respect *Anchitrema* resembles *Eumagacetes* Looss (*Megacetes* Lss). But against this there is the general agreement in the arrangement of the genitalia, the terminal portion of the male duct, the length of the ova and the host being insectivorous animal. Further in some Lecithodendriinae the excretory bladder is not typically V-shaped but has a tendency to become Y-shaped with a very small median stem. It is, however, considered proper to include this genus for the present in Lecithodendriinae.

In his descriptions of trematode parasites, Tubangui in 1928 records a new species of *Platynosomum*, *P. philippinorum*, found parasitic in the Philippine bat, *Scotophilus temnicki*. His identification of the parasite appears to me to be erroneous. I think the trematode belongs to *Anchitrema* because of the armed cuticle, Y-shaped excretory bladder, preacetabular median genital pore (which is situated at oesophageal bifurcation in *Platynosomum*), extracæcal testes (which is shown in his diagram but not mentioned in his description) and the habitat (generally the Dicrocoeliinae are parasitic in liver and gall-bladder). Tubangui describes the cirrus-sac as pear-shaped in his species but does not say whether it is muscular or membranous (the latter being the case in *Anchitrema* while former in *Platynosomum*).

#### EXPLANATION OF THE PLATE

Fig 1, Dorsal view of a mounted specimen of *Pycnporus loossi*, n. sp.

Fig 2, Dorsal view of a mounted specimen of *P. indius*, n. sp.

Fig. 3, Dorsal view of a mounted specimen of *Anchitrema sanguineum*.

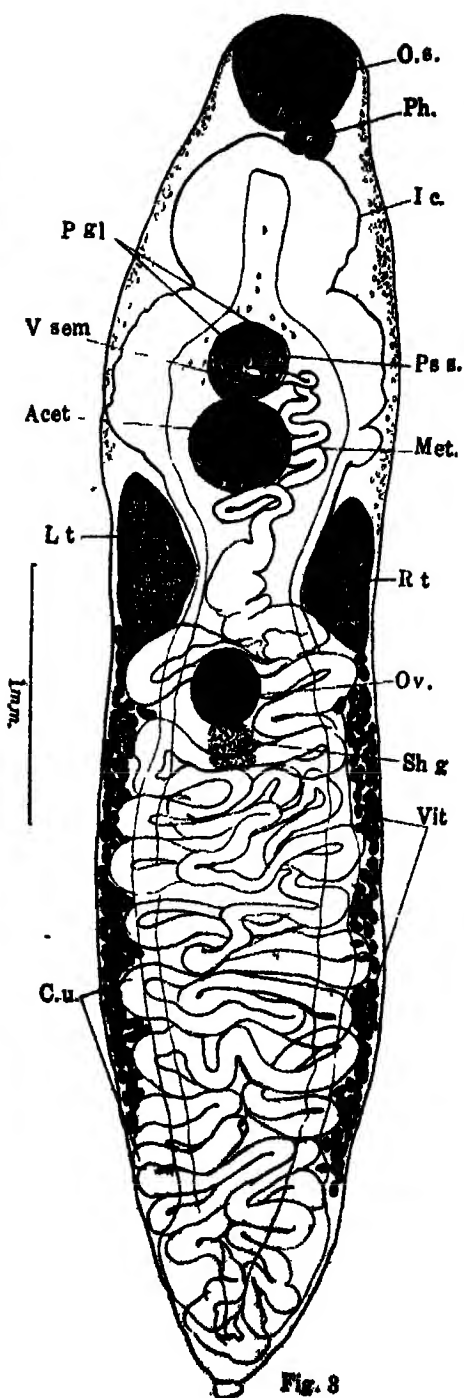
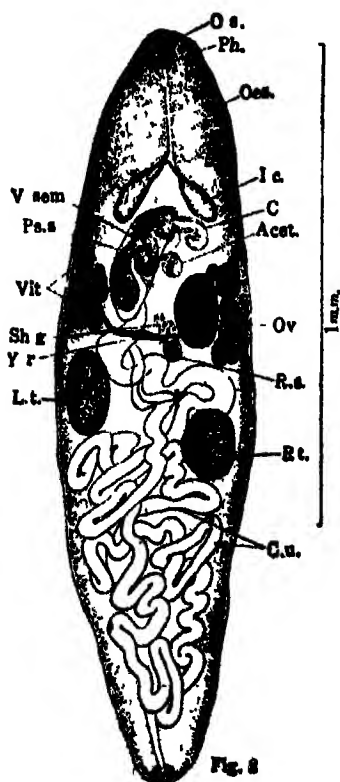
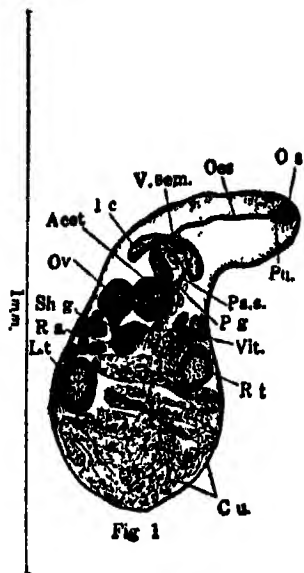


## Key to lettering

acet, acetabulum, c, cirrus, cu, uterine convolutions, d.ej, ductus ejaculatorius; g o, genital opening, i c, intestinal cæcum, l t, left testis, met, metraterm, oes., oesophagus, os, oral sucker, ov, ovary, p g, prostate gland cells, p p, pars prostatica, ph, pharynx, ps s, pseudo-cirrus-sac, r s, receptaculum seminis, r t, right testis, sh g, shell gland complex, v sem, vesicula seminalis, vit, vitellaria, y r, yolk reservoir

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## NEW HEMIURIDS (TREMATODA) FROM INDIAN FRESH-WATER FISHES

**Part 1**—"New Distomes of the Genus *Lecithaster* Luhe, 1901, from  
*Clupea ilisha*"

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Communicated by Dr H R Mehra

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One of the common fresh-water fish in the market in Northern India is *Clupea ilisha*, known as Helsa in vernacular. The fish is found in large numbers in the local rivers for about eight months in the year. It becomes rare towards the end of summer and almost totally disappears during the rainy season. It is found infected with a large number of interesting helminths in different seasons. In winter it is found infected with several interesting trematodes belonging to the sub-families Sterrhurinae, Lecithasterinae, Dinurinae and Fellodistominae and cysts of cestode larvae. In summer the Trematode infection clears off and instead the fish is parasitised by Acanthocephala and Linguatulids. In this paper I give an account of two new species of *Lecithaster*.

The genus was established by Luhe in 1901 for *Dist bothryophoron* Olsson, 1868, which Odhner in 1905 showed to be actually *Dist gibbosus* Rud., 1802. Subsequently the following species have been described under the genus, *Lecithaster*: *L. confusus* Odhner, 1905, *L. stellatus* and *L. galeatus* Looss, 1907, *L. anisotrema* MacCallum, 1921, *L. hindburgi* Layman, 1930, and *L. salmonis* Yamaguti, 1934. The account of the two species described by Looss in 1907, i.e., *L. stellatus* and *L. galeatus*, is very meagre and is insufficient for correct identification. The two species, however, cannot be retained under *Lecithaster* on account of the character of the ovary which, according to Looss, is unlobed. Yamaguti in 1934 described a parasite from the intestine of a Japanese Fish—*Hahchoeres*

*poecilopterus* under the name *L. stellatus* Looss, which differs from Looss' specimen in the character of the ovary which is 4-lobed and the shorter length of the vesicula seminalis which does not extend behind the acetabulum. The Japanese species obviously is a very different parasite from *L. stellatus*. *L. anisotrema* MacCallum has rightly been considered by Manter, 1931, a synonym of *Brachadena pyriformis* Linton, 1910 Yamaguti in 1934 has assigned *L. lindburgi* to *Tubulovesicula* Yamaguti, 1934

### ***Lecithaster indicus*, n sp**

This species represents a common parasite in the intestine of *Chupea vlasha* at Allahabad. The rate of infection in winter is nearly 100% when practically every fish is found harbouring the parasite. The number of parasites in a single host varies from 8 to 20. The distomes live firmly attached to the wall of the intestine and do not come out as soon as the gut is cut open in salt solution. In the living condition they are light brown in colour and lack any marked power of contraction and expansion. When alive they attach themselves by means of their powerful ventral sucker and move their ends in a leech-like manner. In salt solution they can live for 10—12 hours.

The body is muscular, fusiform or spindle-shaped with a nearly uniform diameter, except at the ends which are bluntly pointed. The body is smooth and entirely devoid of spines or cuticular denticulations. Sexually mature worms in balsam mounts measure 0·95—1·7 \* in length and 0·24—0·43 in maximum breadth which lies across the region of the acetabulum. Unicellular cutaneous gland cells are present in fairly large numbers in the preacetabular region behind which they occur only sparsely.

The suckers are well developed and muscular. The sub-terminal oral sucker is slightly broader than long measuring 0·065—0·083 × 0·083—0·11 in size. The acetabulum, 0·16—0·17 in diameter, is situated a little behind the intestinal bifurcation at about the middle of anterior half of body. The oral sucker opens posteriorly into a very small prepharynx visible in sections only. The pharynx is muscular and oval measuring 0·06—0·07 × 0·048—0·063 in size. A short but definite oesophagus of 0·04—0·063 length is present. The caeca are long and sinuous with crenated margins extending posteriorly to a little distance in front of the hinder end. They are equal in length. The oral sucker, prepharynx, pharynx, oeso-

\* All measurements are in mm

phagus and a small length, 0.07—0.1, of the cæca are all lined internally with cuticle.

The testes, two in number, are small, spherical or transversely oval structures with markedly indented outline, situated symmetrically or asymmetrically, one on each side, close behind the acetabulum in the second quarter of body. The right testis, of 0.07—0.09 × 0.07—0.12 size, is slightly smaller than the left which measures 0.9—0.11 × 0.07—0.1 in size. The vesicula seminalis is an undivided bulb-shaped structure of 0.14—0.16 × 0.06—0.12 size lying in the intercæcal space with its posterior two-thirds length extending behind the acetabulum upto the hinder margin of testes. The pars prostatica is a fairly long, 0.16—0.19, tube lined internally by a row of rectangular cells with prominent nuclei, and is surrounded by a large number of flask-shaped prostate gland cells, which, as in other hemiurids, lie free in the parenchyma. Anteriorly it opens into the posterior tip of the sinus sac and after receiving the metraterm from the right side continues into a tubular genital sinus or ductus hermaphroditicus of 0.09—0.1 length. The latter is surrounded by a pyriform sinus sac measuring 0.09—0.1 × 0.04—0.05 in size, i.e., half the length of pars prostatica. The genital sinus opens on the ventral surface at the level of intestinal bifurcation or just in front of it. It is usually median but sometimes is shifted slightly to one side.

The ovary of 0.23—0.33 × 0.1—0.22 size consists of four elongated bulb-shaped lobes all connected together in the centre and measuring 0.1—0.16 × 0.05—0.07 in size. It is situated in the posterior three quarters of the body partly overlapping the cæca. A well developed, bulb-shaped receptaculum seminis of 0.12—0.17 × 0.06—0.09 size is situated in the intercæcal space just in front of the ovary. Laurer's canal is present.

The vitellaria, 0.21—0.24 × 0.12—0.13 in size, consists of seven finger-shaped lobes with saccular distal ends, varying from 0.12—0.17 × 0.03—0.04 in size and are all connected together in the centre. It is situated in the median line close behind the ovary overlapping the cæca. The shell gland complex lies between the ovary and vitellaria.

The uterus is arranged in irregular longitudinal coils extending from the acetabulum to a little distance in front of the posterior end. Terminally the uterus is continued into a short, 0.03 × 0.008, metraterm which enters the sinus sac to form the genital sinus. The male and female ducts do not unite outside the sinus sac. The eggs are numerous, small and operculate, measuring 0.015—0.02 × 0.007—0.01 in size.

The excretory bladder is of the usual hemiurid type, i.e., Y-shaped with the cornua uniting dorsal to the pharynx.

In its relationship the species stands nearest to *L. salmonis* Yamaguti, 1934. But it differs from the latter in the length of the cæca, extent of vesicula seminalis, shape of testes and of ovarian and vitelline lobes, position of genital pore and the much smaller size of eggs

Host—*Clupea ichha*.

Habitat—Intestine.

Locality—Allahabad (Rivers—Ganges and Jumna)

### ***Lecithaster extralobus*, n sp**

The parasite has a smooth, muscular, spindle-shaped body, tapering at both ends. Under slight pressure it measures 1.44 in length and 0.47 in greatest breadth across the vesicula seminalis. Suckers are spherical and muscular. The subterminal oral sucker, of 0.08 diameter, is smaller than the acetabulum which measures 0.16 across and is situated at the junction of the first and second quarters of body. The ratio between oral and ventral suckers is 1:2. Prepharynx and œsophagus are absent. Pharynx highly muscular and globular, 0.06 in size. Cæca first run at right angles to pharynx and then turn downwards extending in a sinuous course to the hinder end. Oral sucker, pharynx and anterior horizontal portion of cæca are all lined internally with cuticle. The cæca are of unequal length, the left being larger extending to posterior tip while the right ends a little in front of the latter.

Testes, two in number, are more or less ovoid in shape and lie asymmetrically, one on each side, behind the acetabulum. The left testis, 0.4 in size, is more cephalad, lying just behind acetabulum while the right of 0.6 size is situated some distance behind ventral sucker in close contact with ovary. Vesicula seminalis is fairly large in size, measuring  $0.17 \times 0.09$ , and is slightly constricted in the middle, situated in the median line obliquely behind acetabulum, extending posteriorly upto anterior margin of right testis and receptaculum seminis. Pars prostatica is a straight tube of  $0.21 \times 0.03$  size, lined internally with flat cells with prominent nuclei and is surrounded all along its length with well developed prostate gland cells which are flask-shaped with long flowing necks. Anteriorly it enters the sinus sac at its posterior tip to continue as the genital sinus after receiving metraterm from the right. The sinus sac measures  $0.09 \times 0.04$  in size. The genital pore is ventral, median, just behind intestinal bifurcation.

Ovary,  $0.23 \times 0.31$  in size, consists of five huge lobes which are all connected in the centre and lies just behind the anterior half of body in

the median line partly overlapping caeca. Receptaculum seminis is a large elongated sac-shaped structure,  $0.17 \times 0.08$  in size, situated slightly to the left side between vesicula seminalis and ovary. Vitellaria,  $0.19 \times 0.29$  in size, consist of eight finger-like lobes, as in *Hysteroleacitha micrororchis* Yamaguti, 1934, with swollen ends lying immediately posterior to ovary. The lobes are all connected anteriorly in the median line and are disposed in a characteristic manner in two groups of four each, one group lying on either side of median line. An irregularly lobed shell gland mass,  $0.04 \times 0.05$ , lies between ovary and vitellaria. Uterus is well developed and stuffed with numerous golden yellow eggs, extending in longitudinal coils from vesicula seminalis to a short distance in front of posterior end. The eggs are oval and thin-shelled, measuring  $0.015 \times 0.01$  in size. The excretory bladder is as in *L. indicus*.

Besides differences in the size of the various organs this species differs from all the species of the genus in the absence of oesophagus, unequal length of caeca, and in having the ovary divided into five instead of four and the vitellaria into eight instead of seven lobes.

Host—*Clupea iksha*.

Habitat—Stomach.

Locality—Allahabad (Rivers—Ganges and Jumna).

I am deeply indebted to Dr H R Mehra under whom this work was carried out for his valuable help and guidance. Thanks are due to Dr D R Bhattacharya for providing me laboratory facilities in the Department. I am grateful to the Trustees of the Lady Tata Memorial Trust, Bombay, for the grant of a research scholarship for investigations in Helminthology.

#### EXPLANATION OF FIGURES

Fig. 1. Ventral view of *Lecithaster indicus*.

Fig. 2 " " " *L. extralobus*.

#### LETTERING

Act.	Acetabulum
G p	Genital pore.
G. s.	Genital sinus.
I. c.	Intestinal caecum.
M.	Metraterm.
O s	Oral sucker.
Oes	Oesophagus
Ov	Ovary.

P gl.	Prostate glands.
P p	Pars prostatica.
Ph	Pharynx.
R sem	Receptaculum seminis
S gl	Shell gland
S s	Sinus sac.
T.	Testis.
Ut	Uterus
V sem	Vesicula seminalis
Vit.	Vitellaria.

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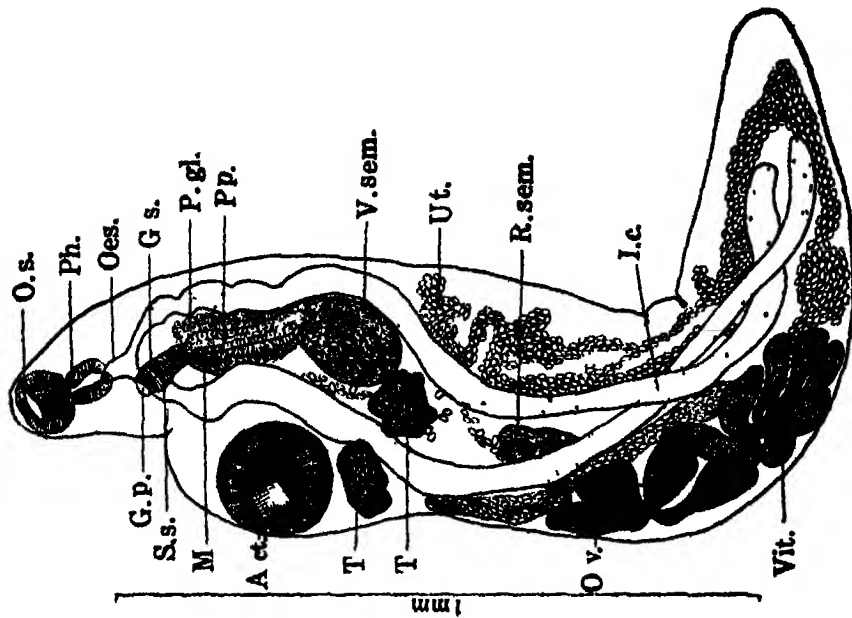


Fig 1

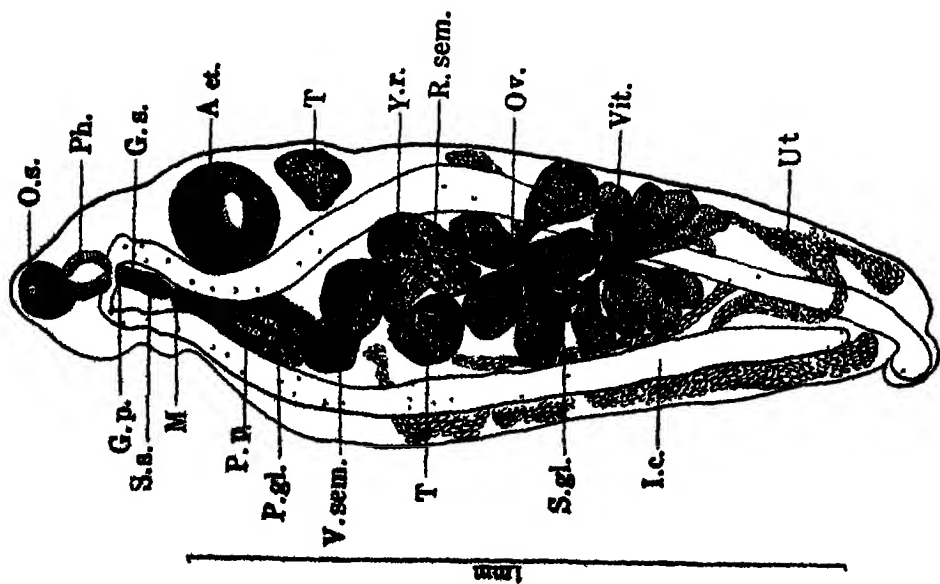


Fig 2

## SOME POLYPORACEÆ FROM THE CENTRAL PROVINCES

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Communicated by Prof J H Mitter

Received March 9, 1935

A large collection of Polyporaceæ was made in 1930 during the rainy season from Jubbulpore, Khandwa, Burhanpur and other places in the Central Provinces. My search for these fungi extended over only a brief period, and it is therefore certain that the collection does not include all the Polyporaceæ likely to occur at these stations during the monsoon. It must also be noted that the collection was more or less confined to these towns and their near vicinities. The fact that a fairly large collection of all the genera of Polyporaceæ could be made in a short time from so limited an area would go to show the abundance of the Polyporaceæ at these places. Almost all the forms collected have been investigated and their structure studied in detail. I am here describing only five of the collected species which deserve a special mention.

### (1) *Polyporus indicus* Mass.

Locality and Habitat—collected from Jubbulpore in August, 1930, growing singly on a log of *Acacia arabica*

Pileus	...	. Stipitate, fan-shaped, thinning out towards the margin, coriaceous when fresh, stiffens on drying
Margin	...	Thin, reflexed and sterile
Upper Surface	..	Rough with wrinkles, concentrically zonate, almost Sulphine yellow in colour, margin of somewhat deeper tinge.
Hymenial Surface	...	Saccardo's umber in colour, pores very minute, angular, and regular. Pore tubes about 1—1.5 c m. long, quite distinct from the context which is Sanford's brown.
Spores	...	Globose, Sanford's brown, about 4.2—5.6 mic. in diameter.

(2) *Polyporus agariceus* Berk—

Locality and Habitat—Collected from Khandwa in August, 1930.  
Growing singly on a wounded branch of *Ficus religiosa*

Pileus	Stipitate, fan-shaped, 2 × 12 cm., partly soft and coriaceous
Margin	Very thin, fertile, wavy and partly reflexed
Upper Surface	Smooth to touch, cobalt-red in colour
Hymenial Surface	Almost of the same colour as the upper surface, pores large, elongated, roughly hexagonal, pore tubes extremely short
Spores	Subhyaline, very small, somewhat sub-globose, 1.4–2.5 mic in diameter

(3) *Polyporus cuticularis*, (Bull.) Pat

Locality and Habitat—collected from Jubbulpore in August, 1930, growing in clusters on a log of wood, and also from Burhanpur in August, 1930.

Pileus	Dimidiate, arc-shaped, about 4–12 cm long, some of them were resupinate, forming scattered patches of varying sizes on the log, and $\frac{1}{2}$ –1 cm thick, hard and brittle in dry condition
Margin	Thick, broad, wavy and fertile.
Upper Surface	Smooth, colour varies in tone, red, scarlet red, and some old specimens of Burnt-Sienna Very thin cuticle, and inconspicuously zonate

Prof. Bose collected *Polyporus Cuticularis* in 1918 from Darjeeling. The upper surface of his specimen was hairy. Dr J H Mitter and R N Tandon collected the same species from Naini Tal in 1928 which was also hairy on upper surface. In my specimen hairs are lacking. Development of hairs in Darjeeling and Naini Tal specimens is probably due to severe cold or frost.

Hymenial Surface	Almost of the same colour as the upper surface, Pores circular, pore-mouths torn, pore tubes about $\frac{1}{4}$ – $\frac{1}{2}$ c. m. long.
Context	... Pale-auburn, fibrous, fairly thin and shining.

Basidia	Shrivelled up, and almost hyaline
Spores	Some roundish, some almost oval, 5—7.5 mic in diameter

(1) *Poria Calcea* (Fr.) Bres=*Poria vulgaris* var *Calceator*

Locality and Habitat—collected from Jubbulpore in August, 1930 Growing as scattered patches only on the bark of a log of wood

Pileus	Resupinate, scattered patches of varying size and thickness, 4—8 m.m thick, coriaceous in fresh state, on drying it becomes somewhat hard and brittle, upper surface smooth and glossy.
Hymenial Surface	White-brown, pores very minute, unequal in size, somewhat angular and not uniform. Pore tubes short
Basidia and spores	Not found

(5) *Fomes pallidus*—Petch

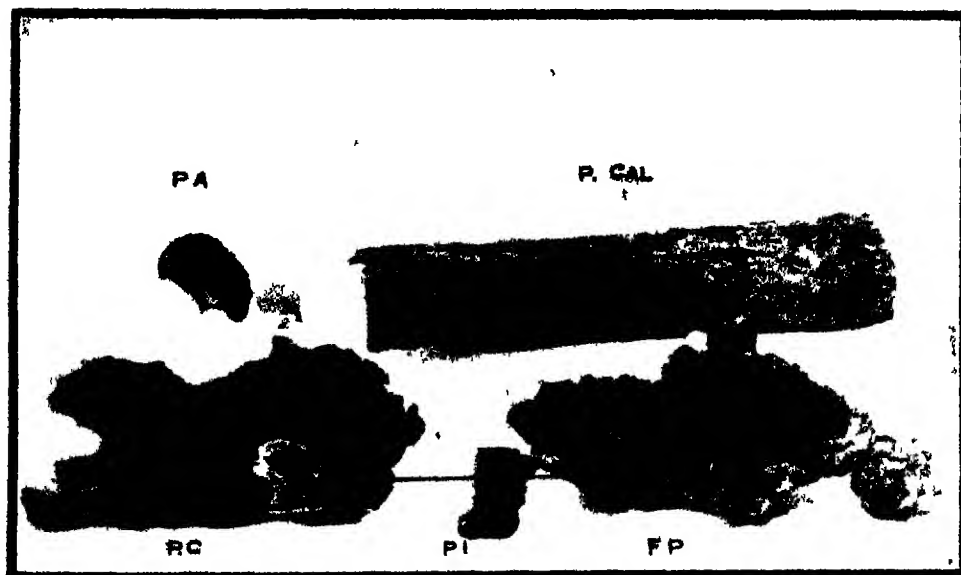
Locality and Habitat—collected from Jubbulpore in August, 1930 from the trunk of a tree

Pileus	Odouriferous, smooth, hard, resupinate with bracket-forming tendency Some of them entirely resupinate, some with bracket formations, varying in size from 1.5—4.5 cm
Margin	In bracket forms it is broad, thick and sterile; in resupinate ones it is thin, wavy and sterile, and mars-yellow in colour
Context ...	Whitish-buff, about 3—1.5 mm thick.
Hymenial Surface ..	Maize-yellow, pores angular and elongated, dissepiments of the pores thick, pore tubes vary in depth from 5—8 mm and concolorous with the context
Spores	Not found.

I am indebted to Prof. J. H. Mitter for his suggestion of the problem and also to Prof. S. R. Bose, who had very kindly identified the collection.

## EXPLANATION OF PLATE I

- P A. Polyporus agariceus, Berk, showing the upper and the hymenial surfaces of the sporophore
- P Cal . Poria calcea (Fr) Bres, = Poria vulgaris Var calceator, showing resupinate patches
- P C . Polyporus cuticularis, (Bull) Pat
- P I Polyporus indicus, Mass
- F P Fomes pallidus, Petch



## DETERMINING SIZES OF MANGUM TERRACE OUTLETS

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Communicated by Mr Mason Vaugh

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The usual method of designing small open channels for agricultural purposes where extreme accuracy is not necessary is (1) to find the quantity of water to be handled in cubic feet per second as determined by the area to be drained and the rate of run-off, and (2) by trial and error, assuming different ditch dimensions, to experiment until a combination of dimensions is found which will handle the necessary amount of water per second and at the same time give the water a velocity which is not excessive for the type of soil in which the channel is to be located

The first of these operations is outlined in the simple formula:

$$Q = \frac{AR}{86,400}$$

in which  $Q$  is the discharge in cubic feet per second,  $A$  is the area to be drained (in square feet), and  $R$  is the depth of water (in feet) to be removed from the soil in twenty-four hours.

*Example* —What will be the discharge in cubic feet per second necessary to remove 6 inches of water from 5 acres of land in 24 hours?

$$A = (5) (43,560) = 217,800 \text{ square feet}$$

$$R = \frac{1}{2} \text{ or } 0.5 \text{ feet}$$

$$\text{then } Q = \frac{(217800)(0.5)}{86,400} = 1.26 \text{ cubic feet per second.}$$

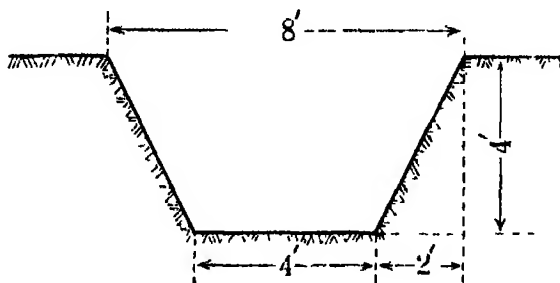
The second operation is performed with the help of *Ellcott's Open-Ditch Formula*, which is

$$V = \sqrt{\left(\frac{a}{p}\right) \left(\frac{3}{2} h\right)}$$

in which  $V$  is the mean velocity in feet per second,  $a$  is the area of the

cross-section of the ditch in square feet,  $p$  is the wetted perimeter of the channel in feet, and  $h$  is the fall along the channel in feet per mile

*Example*.—What will be the mean velocity in an open ditch 8 feet wide and 4 feet deep with 2:1 side slopes and a fall of 20 feet per mile?



$$a = \left( \frac{8+4}{2} \right) (4) = 24 \text{ square feet}$$

$$p = 4 + 2\sqrt{4^2 + 2^2} = 12.94 \text{ feet}$$

$$h = 20$$

$$V = \sqrt{\left( \frac{24}{12.94} \right) \left( \frac{5}{2} \cdot 20 \right)}$$

$$= 7.45 \text{ feet per second}$$

Thus by assuming widths and depths, one can experiment until he finds a combination of width and depth, which, with the fall available, will give the necessary discharge without exceeding the allowable velocity in the soil type concerned

The difficulty with this procedure is that, while it is simpler than the use of the more exact Chery-Kutter formula, it still presents too many complications for the average Intermediate or even BSc graduate in agriculture to apply by himself without more expert help. If the use of the Mangum terrace is to spread into general use as a major method of soil erosion control, some method of deciding on outlet channel dimensions must be devised which will be very simple in application, yet dependable in results

Such a method may be developed by the following procedure

(1) *Standardize the type of ditch surface*

For most Indian conditions a *sodded* channel offers the most advantages. It is productive; the grass may be cut to be used as feed. It is economical, being cheap to construct and requiring none of the materials necessary for wooden

or masonry channels. It resists erosion, having a much more stable surface than any type of soil without vegetation and thus allowing greater velocities without harm to the channel.

(2) *Standardize the ratio of channel width to channel depth*

From the standpoint of cost of excavation, a ditch which is twice as wide as it is deep is most economical. Furthermore, when used with 2:1 side slopes, it gives the maximum discharge with the minimum velocity of any common channel shape.

(3) *Standardize the slope along the ditch.*

If these three standardizations are made, it becomes possible to develop a formula and from it to compile a single table in which anyone can locate the required outlet dimensions if he knows (1) the area to be drained, and (2) the maximum run-off probable in any period of 24 hours.

Every Intermediate or BSc graduate in agriculture should be able to compute areas and the probable run-off in 24 hours is so definitely indicated by geographical location that each student can be shown in the classroom what the maximum probable run-off in his section of the country may be.

*Derivation of the Formula*—The formula used in making this table is a very simple derivation from the two equations already given.

$$(1) \quad Q = \frac{AR}{86,400}$$

$$\text{and } (2) \quad V = \sqrt{\left(\frac{a}{p}\right) \left(\frac{3}{2} h\right)}$$

and upon the third formula that

$$(3) \quad Q = aV$$

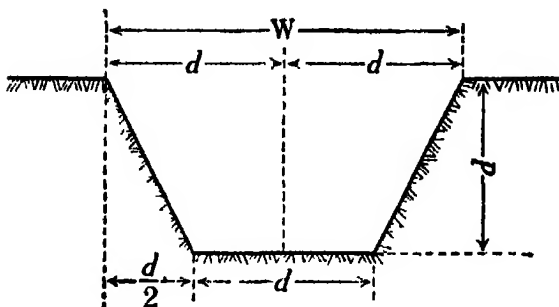
where  $Q$  is the discharge in cubic feet per second,  $a$  is the cross-sectional area of the channel in square feet, and  $V$  is the mean velocity in feet per second.

Standardizing the width of the channel as twice the depth makes it possible to find the cross-sectional area ( $a$ ) and the wetted perimeter ( $p$ ) of the channel in terms of the width ( $w$ ).

$$a = \left\{ \frac{w + \left( w - 2 \frac{d}{2} \right)}{2} \right\} (d)$$



$$= \frac{w + \frac{2w-2d}{2}}{2} (d)$$



Standardized Relationship

$$= \frac{2w-d}{2} (d)$$

$$= \frac{2w-\frac{w}{2}}{2} \left( \frac{w}{2} \right)$$

$$= \left( \frac{3w}{4} \right) \left( \frac{w}{2} \right)$$

$$= \frac{3w^2}{8}$$

$$(I) \quad a = 375 w^2$$

Also

$$p = \left( w - 2 \frac{d}{2} \right) + 2 \sqrt{d^2 + \left( \frac{d}{2} \right)^2}$$

$$= (w - d) + 2 \sqrt{5 \frac{d^2}{4}}$$

$$= w - d + 2 (1.118 d)$$

$$= w + 1.236 d$$

$$= w + 0.618 w$$

$$(II) \quad p = 1.618 w$$

It is obvious that  $h$  (fall in feet per mile) is equal to  $52.8s$  where  $s$  is the % slope (fall in feet in 100 feet) inasmuch as there are 5280 feet in one mile

These values may now be substituted in the Elliott Formula .

$$V = \sqrt{\left( \frac{a}{p} \right) \left( \frac{3}{2} h \right)}$$

with the following results

$$\begin{aligned} V &= \sqrt{\left(\frac{375 \text{ } m^3}{1618 \text{ } m}\right) \left(\frac{3528 \text{ } s}{2}\right)} \\ &= \sqrt{(2317 \text{ } m) (792 \text{ } s)} \\ &= \sqrt{1835 \text{ } m s} \end{aligned}$$

$$(III) \quad V^2 = 1835 \text{ } m s$$

but since  $Q = nV$  (Formula 3, page 394),

$$V = \frac{Q}{n}$$

$$\text{and } V^2 = \frac{Q^2}{n^2}$$

Now  $n = 375 \text{ } m^2$ , (see I), and  $V^2 = 1835 \text{ } m s$ , (see III),

$$\text{Therefore, } 1835 \text{ } m s = \frac{Q^2}{(375 \text{ } m^2)^2}$$

$$1835 \text{ } m s = \frac{Q^2}{1406 \text{ } m^4}$$

$$\text{Then, } 2580 \text{ } m^5 s = Q^2$$

$$m^5 = \frac{Q^2}{258 \text{ } s}$$

$$(IV) \quad \text{And, } m = \sqrt[5]{\frac{Q^2}{258 \text{ } s}}$$

We now have a formula by means of which a table can be made showing for a particular value of  $s$  the width of channel necessary to give a certain discharge.

Since the accepted engineering practice is to design a channel to run '8 full at full capacity, the factor  $5/4$  should be inserted to care for this. The formula then assumes its final form.

$$(V) \quad m = \frac{5}{4} \sqrt[5]{\frac{Q^2}{258 \text{ } s}}$$

#### *Limiting Velocities :*

It is impossible to keep the *slope* of the channel and the *relation of width to depth* constant without varying the velocity of flow. For this reason it is necessary to determine the point at which the slope must be

reduced in order not to exceed the velocity at which erosion of the channel itself would occur.

No data on the allowable velocity in *sodded* channels is known to this writer. In volume 2 of his book "Irrigation Practice and Engineering," Etchverry gives the following as maximum values of mean velocities safe against erosion

<i>Material</i>	<i>Mean Velocity</i> (in feet per second)
Very light pure sand, quicksand character	0.75 to 1.00
Very light, loose sand	1.00 to 1.50
Coarse sand or light sandy soil	... 1.50 to 2.00
Average sandy soil	2.00 to 2.50
Sandy loam	... 2.50 to 2.75
Average loam, alluvial soil, volcanic ash soil	.. 2.75 to 3.00
Firm loam, clay loam	. 3.00 to 3.75
Stiff clay soil, ordinary gravel soil	... 4.00 to 5.00
Coarse gravel, cobbles, shingles	... 5.00 to 6.00
Conglomerates, cemented gravel, soft slate, tough hardpan, soft sedimentary rock	6.00 to 8.00
Hard rock	... 10.00 to 15.00
Concrete	15.00 to 20.00

In view of this data, it has been decided to use a limiting value of 7.5 feet per second in these tables. This may seem to be too high. It has been chosen with regard to the following considerations.

- (1) That a terrace outlet is used only a very small part of each year
- (2) That the periods when the channel will be filled *to capacity* will come perhaps once in two or three years and will then last only a few hours
- (3) That the maximum flow will occur at that time of year when the grass is growing rapidly so there should be practically complete sod covering on the soil.

Using, then, a value of 7.5 feet per second as a maximum velocity we arrive at the allowable width of channel as follows

In developing formula III, page 396, we have the relationship.

$$V = \sqrt{18.35 ws}$$

By assigning values to *s*, and replacing *V* with 7.5 feet per second, we can find the desired maximum channel width allowable

Because of ease of calculation by the student or graduate constructing a channel and of adequacy to most conditions, slopes of 1% and 0.5% have been decided upon for this table. For the 1% slope then, and the maximum velocity of 7.5 feet per second, the limiting value of  $w$  is found

$$V = \sqrt{18.35 s w}$$

$$7.5 = \sqrt{18.35 w} \quad (1)$$

$$7.5 = 4.28 \sqrt{w}$$

$$w = \left( \frac{7.5}{4.28} \right)^2$$

$w = 3.06$  feet, which is the maximum width of a channel when  $n = 2d$ ,  $s = 1\%$ , side slopes are 2:1; surface of the channel is sodded; and the maximum mean velocity is 7.5 feet per second

Similarly, for a 0.5% slope:

$$V = \sqrt{18.35 w s}$$

$$7.5 = \sqrt{18.35 w (0.5)}$$

$$7.5 = \sqrt{9.175 w}$$

$$7.5 = 3.03 \sqrt{w}$$

$$w = \left( \frac{7.5}{3.03} \right)^2$$

$w = 6.13$  feet, which is the maximum width of a channel when  $n = 2d$ ,  $s = 0.5\%$ , side slopes are 2:1; surface of the channel is sodded, and the maximum mean velocity is 7.5 feet per second.

Since, however, the channel widths shown in the table are to be  $5/4$  the width and depth necessary for capacity operation, these limiting widths will be shown as  $5/4$  of the above values and will become:

For 1% slopes . . . 3.83 feet

For 0.5% slopes . . . 7.66 feet

#### *Compilation of Table*

With the foregoing data we may now form the table desired. Table I shows the value of  $Q$ , or the necessary discharge in cubic feet per second, for different areas and to handle different maximum rates of

run-off. Table II gives  $w$ , the necessary width of channel for these same areas and maximum rates of run-off.

The conditions represented by the blank spaces at the upper left-hand corner on Table II are those in which less than 1 cubic foot of water needs to be handled and which would therefore demand only a very small ditch. Under such conditions it is probably unnecessary to establish a 1% slope for the outlet but a sodded strip 4 feet wide and 9 inches lower in the center than along the two sides and following the slope of the field will probably be sufficient.

As noted in Table II, the central portion of the table between the two heavy dividing lines pertains to channels with a slope of 1%, while the small section below the second heavy line and in the lower right-hand corner of the table pertains to channels with a 0.5% grade.

Table I

VALUES OF  $Q$ 

*Inches of Maximum Run-off in 24 Hours*

		1	4	8	12	16	20
	1	.042	.168	.336	.504	.672	.840
	2	.084	.336	.672	1.008	1.344	1.680
	4	.168	.672	1.344	2.016	2.688	3.360
	6	.252	1.008	2.016	3.024	4.032	5.040
	8	.336	1.344	2.688	4.032	5.376	6.720
	10	.420	1.680	3.360	5.040	6.720	8.400
	12	.504	2.016	4.032	6.048	8.064	10.080
	14	.588	2.352	4.704	7.056	9.408	11.760
	16	.672	2.688	5.376	8.064	10.752	13.440
Area	18	.756	3.024	6.048	9.072	12.096	15.120
	20	.840	3.360	6.720	10.080	13.440	16.800
in	22	.924	3.696	7.392	11.068	14.784	18.480
	24	1.008	4.032	8.064	12.096	16.128	20.160
Acres	26	1.092	4.368	8.736	13.104	17.472	21.840
	28	1.176	4.704	9.408	14.112	18.816	23.520
	30	1.260	5.040	10.080	15.120	20.160	25.200
	35	1.470	5.880	11.760	17.640	23.520	29.400
	40	1.680	6.720	13.440	20.160	26.880	33.600
	45	1.890	7.560	15.120	22.680	30.240	37.800
	50	2.100	8.400	16.800	25.200	33.600	42.000
	55	2.310	9.240	18.480	27.720	36.960	46.200
	60	2.520	10.080	20.160	30.240	40.320	50.400

Table II

VALUES OF *W**Maximum Run-off in Inches in 24 Hours*

		1	4	8	12	16	20	
Area in Acres	1	Regular channel						
	2	unnecessary						
	4							
	6							
	8	See p. 399	1.04	1.37	1.61	1.81	1.98	
	10		1.16	1.54	1.81	2.03	2.22	
	12		1.27	1.68	1.98	2.22	2.42	
	14		1.37	1.81	2.12	2.38	2.60	
	16		1.46	1.92	2.26	2.54	2.79	Slope is 1%
	18		1.54	2.03	2.38	2.67	2.92	
	20		1.61	2.12	2.50	2.80	3.06	
	22		1.68	2.22	2.60	2.92	3.20	
	24		1.74	2.30	2.69	3.03	3.33	
	26	1.04	1.81	2.38	2.80	3.15	3.44	
	28	1.07	1.88	2.46	2.89	3.24	3.55	
	30	1.10	1.92	2.54	2.98	3.34	3.65	
		1.13	1.98	2.60	3.06	3.44	3.76	
	35	1.20	2.10	2.79	3.25	3.65	4.58	
	40	1.27	2.22	2.92	3.44	4.43	4.85	Slope is 0.5%
	45	1.33	2.32	3.06	3.60	4.65	5.08	
	50	1.39	2.42	3.20	3.76	4.85	5.30	
	55	1.44	2.51	3.33	4.44	5.06	5.50	
	60	1.50	2.60	3.44	4.65	5.21	5.70	

NOTE — For practical use there is no advantage in having this table carried further than one decimal place as tenths of feet are as close as most will come to accurate construction.

## SUMMARY

We now have a simple yet dependable guide to sizes for open channel terrace outlets. By using the column in Table II which serves the maximum run-off in 24 hours probable in the locality in which the channel is to be constructed, one may, by simply knowing the area to be served, read directly the width and slope which the channel should have. It has been decided that the depth shall be one-half of the width; that the side slopes shall be 2:1 and that the surface of the channel shall be sodded. All of the necessary data have been provided.

# **BUSINESS MATTERS**

**PATRON**

**His Excellency Sir Harry Haig,**  
*The Governor of the United Provinces of Agra and Oudh*

**HONY. FELLOWS**

**The Hon'ble Sir J P Srivastava, Kt, M Sc (Tech.)**  
*The Minister of Education,*  
*The United Provinces of Agra and Oudh*

**Pandit Madan Mohan Malaviya, L.L.D.,**  
*Vice-Chancellor,*  
*Benares Hindu University, Benares*



# **Business Supplement**

## **ANNUAL MEETING**

The Annual Meeting of the Academy of Sciences was held in the Physics Lecture Theatre, Muir College Buildings, Allahabad, at 3 p.m. on Wednesday, February 27, 1935. Dr. Sir L. L. Fermor, Kt, O.B.E., D.Sc., A.R.S.M., M.Inst.M.M., F.G.S., F.A.S.B., F.R.S., Director, Geological Survey of India, Indian Museum, Calcutta, presided over the function. Prof. A. C. Banerji, the General Secretary, read the Annual Report of the Academy of Sciences for 1934.

Dr. K. N. Bahl, D.Sc., D.Phil., the President of the Academy, read his address. Dr. Sir L. L. Fermor, then delivered his address.

Dr. P. L. Srivastava proposed a vote of thanks to the outgoing President, Dr. K. N. Bahl, and the outgoing Secretary, Mr. A. C. Banerji, and Dr. Tara Chand seconded the vote. Prof. M. N. Saha proposed a vote of thanks to Dr. Sir L. L. Fermor and Dr. H. R. Mehra seconded it.

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## **SECRETARIES' REPORT**

**Prof. A. C. Banerji**

We have the honour to submit the following report on the working of the Academy during the period beginning from the 1st of January 1934 and ending on the 31st of December, 1934.

The Third Annual Meeting of the Academy of Sciences was held in the Vizianagram Hall, Muir College Buildings, Allahabad, on Saturday, January 20, 1934 at 4 p.m. The Hon'ble Sir Shah Mohammad Sulaiman, Kt, M.A., LL.D., Chief Justice, High Court, Allahabad, presided over the function. His Excellency Sir William Malcolm Hailey, the Patron of the Academy, and the Hon'ble Mr. J. P. Srivastava, the Minister of Education, U.P., sent messages befitting the occasion.

We are glad to record the steady progress that the Academy is making both as regards its membership and the standard of its publications. The Academy has now on its roll 118 members of whom 25 are

**Non-resident members** The journal of the Academy has received good recognition in India as well as outside India. Its name has now been changed from "The Bulletin of the Academy of Sciences" to "The Proceedings of the Academy of Sciences, U P." We are now receiving 104 foreign and Indian scientific journals in exchange

We are much indebted to Government for the non-recurring grant of Rs 2,000, which was received in December last, for the financial year 1934-35. The Academy also owes a debt of gratitude to Sir Shah Mohammad Sulaiman for his handsome donation of Rs 400 to it. Sir Shah Mohammad read a paper on the Mathematical Theory of Relativity before the Academy which has attracted notice of Scientists in India and abroad, and an appreciative note on his theory was published in the American scientific journal "SCIENCE."

It is a matter of genuine pleasure to every Scientist that owing to the efforts of Dr. L. L. Fermor, an honourable compromise between different groups of Scientists in India has been effected and the National Institute of Sciences, India, the All-India co-ordinating scientific body, has now been founded. We are glad to mention that the U P Academy of Sciences has all along given active support to the establishment of such a body and has agreed to co-operate fully with the newly formed National Institute. We have been able to publish five issues of our journal during the year 1934. The number of original publications which we are receiving from different research centres of the country provides sufficient material for a few more issues, but our activities in this direction are restricted on account of financial difficulties. We have not yet been able to organise a Science Library nor publish a popular scientific journal. We hope and trust that Government will place us under further obligation by sanctioning a recurring grant of Rs 4,000 per annum, so that we may give effect to our ideas and extend the sphere of our useful activities. The need for a building of the Academy is urgently felt, and an appeal for raising money for this purpose will have to be issued soon. With the help of Government, the Universities of these provinces, and generous public, we hope it will be possible for us to construct a suitable building for the Academy before long.

The Academy accepted with thanks the gift of eight volumes of Philosophical Magazine and Journal of Science from an anonymous donor through Mr Ram Niwas Rai, M.Sc. Three new Fellows, *viz.*, Prof J C. Ghosh of Dacca, Drs. Shri Ranjan and B. N. Prasad of Allahabad, have been elected. There is a general consensus of opinion among the members of the Academy that the number of Fellows of our Academy should

not be restricted to thirty, but should be increased considerably. A committee has been formed to consider this question, to recommend changes in our rules and regulations, and to suggest a more suitable name for our Academy.

Our thanks are due to Dr Narendranath Ghatak, DSc, for kindly helping us in the publication of our journal "The Proceedings of the Academy of Sciences, UP". He has now been appointed its Assistant Editor. We also wish to express our thanks to the other Office-bearers and the members of the Council of the Academy for their ungrudging help and active co-operation.

## ABSTRACTS OF THE PROCEEDINGS

The list of the Office-bearers and Members of the Council to which the management of the affairs of the Academy was entrusted for the year 1934-35 is given in appendix A

Appendix B contains the list of names of members who were on the roll of the Academy on March 31st, 1935.

The Council expressed its deep gratitude to the Government for the non-recurring grant of Rs 2,000 awarded to the Academy for the year 1934-35

The Council considered the resolution of the General Committee of the Indian Science Congress about the adoption of Metric System throughout the whole of India and it recommended that the Government of India should be requested to adopt the System as far as possible through India

The Council resolved that the U P Academy of Sciences beg to represent strongly that proper consideration was not given by the Academy Committee of the Indian Science Congress Association to the claims of the Scientists of the United Provinces and the Punjab for adequate representation in the matter of Fellowships of the proposed National Institute of Sciences (India)

The Council resolved that in the opinion of the members of the U P Academy of Sciences, the name of the central body should be The National Academy of Sciences of India instead of the proposed name, The National Institute of Sciences (India)

The Council resolved that the U. P. Academy of Sciences beg to lodge its protest against the use of the name—Indian Academy of Sciences by the Bangalore body as the activity of this body is mainly local and confined to South India Further the Council was of opinion that pressure should be put on the Bangalore body to change its name to the South Indian Academy of Sciences

The above three resolutions were confirmed by the General Body of the Academy

The Council resolved that an Assistant Editor should be appointed who would be responsible to the Editorial Board for bringing out the Proceedings of the Academy of Sciences in proper form

The Council gratefully acknowledged the receipt of Rs. 400 from the Hon'ble Sir Shah Mohammad Sulaiman, Kt., M.A., LL.D., Chief Justice, High Court, Allahabad, as donation to the Academy.

The Council passed the following Rules regarding the publication of papers in the Proceedings of the Academy of Sciences, U P —

1 The paper should be at once sent to the local Editor who should always be the first referee

2. The paper should be referred to a second referee along with the opinion of the local Editor. The second referee should be requested to send his report on the paper within 10 days of the date of receipt

3 Stamped covers for sending back the articles should be despatched along with the article to the second referee

4 If the two reports are unanimous that the paper is in a form suitable for publication it should be sent to the press for printing

5 If there is any difference of opinion, the paper should be referred to a third referee by the local Editor. The decision of the majority regarding the publication of the paper will prevail

6 If the referees recommend the publication of the paper in an abridged or altered form the author should be requested to alter the paper accordingly

7 Every author should send one copy of the paper

8 Every paper should be accompanied by a summary not exceeding 300 words

9 When a paper is received it should at once be acknowledged

10 A referee should be a man who will, as far as possible, be an expert on the subject. He need not necessarily be a member of the Academy of Sciences, U P

11. As far as possible the papers should be published in order of their dates of receipts

The Academy of Sciences, U. P, passed a resolution of condolence in its Ordinary Meeting at the sad and sudden demise of Prof. Ganesh Prasad, the eminent Mathematician and Educationist of India and conveyed its sympathies to the members of the bereaved family

It was resolved by the Fellows of the Academy of Sciences, U P, that the Council of the Academy be requested to effect such changes in the constitution as will enable the Academy to increase the number of fellows from thirty to one hundred

The following three members were elected Fellows of the Academy in the Fellows' Meeting held on November 28, 1934.

1 Prof. J. C. Ghosh, D Sc, Professor of Chemistry, Dacca University, Dacca.

2. Dr. Shri Ranjan, D Sc (Toulouse), Reader in Botany, Allahabad University, Allahabad

3 Dr B N Prasad, M.Sc, D Sc (Paris), Ph D , Mathematics Department, Allahabad University, Allahabad

The following members were elected Office-bearers and the Members of the Council for the year 1935 in the Annual Meeting held on February 27, 1935 :

**President**

- 1 N R Dhar, DSc, F I C, I E S

**Vice-Presidents :**

- 2 Prof K N Bahl, DSc, D Phil  
3 Prof A C Banerji, M A, MSc, F R A S, I E S

**Hony. Treasurer :**

- 4 Dr H R Mehra, Ph D

**General Secretaries :**

- 5 Dr S. M. Sane, B Sc, Ph D  
6 Dr P L Srivastava, M A, D. Phil.

**Foreign Secretary :**

- 7 Prof B Sahni, D Sc, Sc D, F L S, F A S B

**Other Members of the Council :**

- 8 Prof K C Mehta, Ph D.  
9 Prof M N Saha, F R. S  
10 Prof S S. Joshi, D Sc  
11 Prof Ch Wali Mohammad, M A, Ph D, I E S  
12 Dr Shri Ranjan, D Sc  
13 Dr Rudolf Samuel, Ph D  
14 Prof J A. Strang, M.A  
15 Prof D R Bhattacharya, D Sc, Ph D, F Z S  
16 Prof K. C Pandya, D Sc

**APPENDIX A**  
**LIST OF OFFICE-BEARERS AND MEMBERS OF THE COUNCIL**  
**1934**

**President**

Prof K N Bahl, D Sc, D Phil

**Vice-Presidents**

Prof M N Saha, D Sc, F R S, F A S B

Prof B Sahni, D Sc, Sc D, F I. S., F A S

**Hony. Treasurer**

Prof D R Bhattacharya, M Sc, D Sc, Ph D

**General Secretaries**

Prof P S MacMahon, B Sc, M Sc, F I C.

Prof A C Banerji, M A, M Sc, F A S B, I E S

**Foreign Secretary**

Prof. N R Dhar, D Sc, F I C, I. E. S

**Other Members of the Council**

Prof Nihal Karan Sethi, D Sc.

Dr. S S Nehru, M A., Ph D., I. C. S.

Prof. C A King, B Sc, A R C Sc, M I M E

Prof. Ch Wali Mohammad, M A, Ph D, I. E. S

Dr. H. R. Mehra, Ph D

Prof Rudolf Samuel, Ph. D

Dr. S M. Sane, B.Sc, Ph D

Prof C Maya Das, B Sc, M A, I A S.

Prof K C Pandya, D Sc.

## APPENDIX B

### ORDINARY MEMBERS

R—Resident    N—Non-Resident

\*—Denotes a Fellow

†—Denotes a Fellow of the National Institute of Sciences, India

#### Alphabetical List of Ordinary Members

Date of Election		
17-4-1931	R	Asundi, (R K ), Ph D , Reader, Physics Department, Muslim University, Aligarh
1-1-1930	{R*	Bahl, (K.N.), D Phil, D Sc., Professor of Zoology, Lucknow University, Lucknow
1-1-1930	†R*	Banerji, (A C ), M A, M Sc., F R A S , I E S , Professor of Mathematics, Allahabad University, Allahabad
29-2-1932	R	Banerji, (G N ), The Scientific Instrument Company Ltd., Albert Road, Allahabad
22-12-1932	†N	Banerji, (S K ), D Sc, Meteorological Office, Ganeshkhind Road, Poona 5.
17-4-1931	N	Basu, Saradindu, M Sc, Meteorologist, Ganeshkhind Road, Poona 5.
19-3-1931	R	Bhargava, Saligram, M.Sc, Reader, Physics Department, Allahabad University, Allahabad
17-4-1931	R	Bhargava, Vashishtha, M Sc., I C.S., Assistant Magistrate and Collector, Budaun
17-4-1931	R	Bhatia, (K B ), I C.S, Joint Magistrate, Shahjahanpur
21-4-1933	†N*	Bhatnagar, (S.S.), D Sc, Professor of Chemistry, Government College, Lahore
20-12-1934	R	Bhattacharya, (A K.), D Sc, Chemistry Department, Allahabad University, Allahabad
1-1-1931	†R*	Bhattacharya, (D.R), M.Sc, Ph.D., Docteur ès Sciences, Professor of Zoology, Allahabad University, Allahabad
17-4-1931	R	Bhattacharya, (D P), M Sc., Bareilly College, Bareilly.
3-4-1933	R	Chand, Tara, M A, D Phil., Principal, K. P University College, Allahabad
29-2-1932	R	Charan, Shyama, M.A , M.Sc., Agra College, Agra.



Date of Election		Alphabetical List of Ordinary Members
1-1-1930	R*	Chatterji, (G), M Sc, Meteorologist, Upper Air Observatory, Agra
17-4-1931	R	Chatterji, (K P), M Sc, A I C, F.C S, Reader, Chemistry Department, Allahabad University, Allahabad
17-4-1931	R	Chatterji, (A C), D.Sc, Chemistry Department, Lucknow University, Lucknow
9-2-1934	R	Chaturvedi, Champa Ram, Pandit, Professor of Mathematics, St John's College, Agra
19-3-1931	R	Chaudhury, Rabindra Nath, M Sc, M.A, Mathematics Department, Allahabad University, Allahabad
17-1-1931	R	Chaudhury, (H P.), M Sc, Lucknow University, Lucknow
19-3-1931	R	Das, Ramsaran, D Sc, Zoology Department, Allahabad University, Allahabad
17-4-1931	R	Das, C Maya, M A, B Sc, I A.S., Principal, Agricultural College, Cawnpore
28-10-1932	N	Das, (A K.), D Sc, Alipore Observatory, Alipore, Calcutta
22-12-1932	N	Das, (B K.), D Sc, Professor of Zoology, Osmania University, Hyderabad, Deccan
15-9-1931	R	Dasannacharya, (B), Ph D, Professor of Physics, Benares Hindu University, Benares
17-4-1931	R	Deodhar, (D B), Ph D, Reader, Physics Department, Lucknow University, Lucknow
17-4-1931	R	Dey, (P K), M Sc, I A S, Plant Pathologist to Government, United Provinces, Nawabganj, Cawnpore
29-2-1932	R	Deb, Suresh Chandra, D Sc, Research Physicist, Bose Institute, Calcutta
1-1-1930	†R*	Dhar, (N R), D Sc, Docteur ès Sciences, F I C, Professor of Chemistry, Allahabad University, Allahabad
19-3-1931	R	Dutt, (S K), M Sc, Zoology Department, Allahabad University, Allahabad
17-4-1931	R	Dutt, (S.B), D.Sc, Reader, Chemistry Department, Allahabad University, Allahabad.
28-10-1932	R	Dutt, (A K.), D Sc, Bose Institute, Calcutta
22-2-1933	R	Ghatak, Narendranath, M.Sc, D.Sc, Chemistry Department, Allahabad University, Allahabad
19-4-1931	R	Ghosh, (B N.), M Sc, St. Andrew's College, Gorakhpur.

Date of  
Election

## Alphabetical List of Ordinary Members

8-11-1933	†N*	Ghosh, (J C), D Sc, The University, Dacca
19-3-1931	R	Ghosh, (R N), D.Sc., Physics Department, Allahabad University, Allahabad
19-3-1931	R	Ghosh, Satyeshwar, D Sc, Chemistry Department, Allahabad University, Allahabad
15-9-1931	N	Gogate, (D V), M.Sc, Baroda College, Baroda
15-9-1931	R	Gordon, (C.B.), B A, Christ Church College, Cawnpore
17-4-1931	R	Gupta, (B M), Ph D, Deputy Public Analyst to Government, United Provinces, Lucknow
21-12-1931	R	Hansen, (W.J.), M A, Allahabad Agricultural Institute, Naini, E I R., Allahabad
17-4-1931	R	Higginbottom, Sam, D.Phil., Principal, Allahabad Agricultural Institute, Naini, E I R., Allahabad
17-4-1931	R*	Hunter, Robert, (F), D Sc., Ph D, Professor of Chemistry, Muslim University, Aligarh
3-4-1934	R	Joshi, (A D), P.E.S, Lecturer, Training College, Allahabad
21-12-1931	R	Joshi, (S S), D.Sc, Professor of Chemistry, Benares Hindu University, Benares.
15-9-1931	N	Kichlu, (P.K), D Sc, Department of Physics, Government College, Lahore.
1-1-1930	†R*	King, (C.A.), BSc (Hons), A R C.Sc., M I M.E, Principal, Engineering College, Benares Hindu University, Benares.
21-4 1933	N	Kishen, Jai, M Sc., Professor of Physics, S D. College, Lahore
9-2-1934	N	Kothari, (D S), M Sc., Ph D, Professor of Physics, The University, Delhi
3-4-1934	†R	Krishna, Shri (Dr), Chemist, Forest Research Institute, New Forest, Dehra Dun
5-10-1933	R	Kureishy, (A M), M A Reader in Mathematics, Muslim University, Aligarh.
1-1-1930	R*	Luxmi Narayan, D Sc., Reader, Mathematics Department, Lucknow University, Lucknow.
1-1-1930	†R*	MacMahon, (P.S.), B Sc. (Hons), M Sc., Professor of Chemistry, Lucknow University, Lucknow
26-9-1934	R	Malaviya, Braj Kishore, M.Sc., Lok Nath, Allahabad

Date of Election	Alphabetical List of Ordinary Members	
1-1-1930	†R*	Mathur, (K K), B.Sc (Hons), A R S M, Professor of Geology, Benares Hindu University, Benares
1-1-1930	†R*	Mehta, (K C), Ph D, M Sc, Agra College, Agra
1-1-1930	R*	Mitter, (J H), M Sc, Ph D, Professor of Botany, Allahabad University, Allahabad
15-9-1931	R	Mathur, (L P), M Sc, St John's College, Agra
8-11-1933	N	Mathur, Ram Behari, M Sc, Professor of Mathematics, St Stephen's College, Delhi
19-3-1931	R	Mazumdar, Kanakendu, D Sc, Physics Department, Allahabad University, Allahabad
19-3-1931	†R*	Mehra, (H R), Ph D, Reader, Zoology Department, Allahabad University, Allahabad.
21-12-1931	R	Mehta, (N C), I C S, Collector, Muzaffarnagar, U P
21-4-1933	N	Mela Ram, M Sc, Asst Professor of Physics, Foreman Christian College, Lahore
21-4-1933	N	Mukerjee, Ashutosh, M A, Principal, Science College, P O Bankipore (Patna)
22-2-1933	R	Narliker, (V V), M A, Professor of Mathematics, Benares Hindu University, Benares
17-4-1931	R	Nehru, (S S), M A, Ph D, I C S, M L C, Deputy Secretary to Government, U.P, Publicity Department, Lucknow
17-4-1931	R	Panday, (K.C), D Sc, St John's College, Agra
3-4-1933	N	Parija, (P K), M A, I E S, Ravenshaw College, Cuttack
5-10-1933	R	Prasad, Gorakli, D Sc, Reader in Mathematics, Allahabad University, Allahabad
21-4-1933	N	Prasad, Kamta, M A, M Sc, Professor of Physics, Science College, P O Bankipore (Patna)
15-9-1931	N	Prasad, Mata, D.Sc, Royal Institute of Science, Bombay
3-4-1933	R*	Prasad, Badrinath, Ph.D, Docteur ès Sciences, Mathematics Department, Allahabad University, Allahabad.
17-4-1931	R	Puri, (B D), M A., Thomason Civil Engineering College, Roorkee
22-12-1932	†N	Qureshi (M.), M.Sc., Ph.D., Professor of Chemistry, Osmania University College, Hyderabad, Deccan.

Date of  
Election

## Alphabetical List of Ordinary Members

20-12-1934	R	Rai, Ram Niwas, M Sc., Physics Department, Allahabad University, Allahabad
3-4-1933	R	Raja Ram, M.A, B E., Malarial Engineer, Kasauli
19-3-1931	R*	Ranjan, Shri, M Sc., Docteur ès Sciences, Reader, Botany Department, Allahabad University, Allahabad
15-9-1931	N	Rao, A Subba, D Sc, Medical College, Mysore
22-2-1933	N	Rao, G Gopala, B A, M Sc, Chemistry Department, Andhra University, Waltair.
21-12-1931	R	Rao, D H Ramchandra, B E, A.M.I.E, Engineer, Allahabad University, Allahabad
11-3-1934	N	Rao, K. Rangadhama, D.Sc., Physics Department, Andhra University, Waltair
22-2-1933	N	Ray, Bidhubhusan, D Sc, 92 Upper Circular Road, Calcutta
21-12-1931	R	Ray, Satyendra Nath, M Sc., Physics Department, Lucknow University, Lucknow.
1-1-1930	R*	Richards, (P.B.), A.R.C.S, F.E.S, Entomologist to the Government, United Provinces, Cawnpore.
1-1-1930	†R*	Saha, (M.N.), D.Sc, F.R.S., F.A.S.B, F Inst P, P.R.S, Professor of Physics, Allahabad University, Allahabad
29-2-1932	R	Saha, Jogendra Mohan, M.Sc., Manager, Srikrishna Desi Sugar Works, Jhusi, (Allahabad)
1-1-1930	†R*	Sahni, (B), D Sc, Sc D., F L.S, F.A.S.B, Professor of Botany, Lucknow University, Lucknow
17-4-1931	R*	Samuel, Rudolf, Ph D., Professor of Physics, Muslim University, Aligarh.
17-4-1931	R	Sane, (S.M), B Sc., Ph D., Reader, Chemistry Department, Lucknow University, Badshah Bagh, Lucknow
3-4-1933	R	Sen, (K.C.), D.Sc., Imperial Institute of Veterinary Research, Muktesar, Kumaun
20 12-1934	N	Sen Gupta, (P.K), M.Sc., Professor of Physics, Rajaram College, Kolhapur (Bombay Presidency)
21-4-1933	N	Seth (J.B.), M A., Government College, Lahore.
17-4-1931	R	Seth, (S.D), M.Sc., Christ Church College, Cawnpore.

Date of  
Election

## Alphabetical List of Ordinary Members

1-1-1930	R*	Sethi, (R L), M Sc., M R A S, Economic Botanist to Government, United Provinces, Cawnpore
19-3-1931	R	Sethi, Nihal Karan, D Sc, Agra College, Agra
3-4-1934	R	Shah, (S M), M A (Lond), Mathematics Department, Muslim University, Aligarh, U P
15-9-1931	R	Sharma, Ram Kishore, M Sc, Physics Department, Ewing Christian College, Allahabad
3-4-1933	N	Siddiqi, (M R), Ph D, Professor of Mathematics, Osmania University, Hyderabad, Deccan
3-4-1933	R	Siddiqui, Mohd Abdul Hamid, M B B S, M S, F R C S, D L O, Professor of Anatomy, King George's Medical College, Lucknow
17-4-1931	R	Singh, Avadhesh Narain, D Sc, Department of Mathematics, Lucknow University, Lucknow
17-4-1931	N	Soonawala, (M F), M Sc, Maharaja's College, Jaipur (Rajputana)
19-3-1931	R*	Srivastava, (P L), M A, D Phil, Reader, Mathematics Department, Allahabad University, Allahabad
10-8-1933	R	Srivastava, (R C), B Sc (Tech), Sugar Technologist, Imperial Council of Agricultural Research, India, Cawnpore
15-9-1931	N	Srikantia, (C), B A, D Sc, Medical College, Mysore
19-12-1933	R	Strang, (J A), M A, B Sc, Professor of Mathematics, Lucknow University, Badshah Bagh, Lucknow
24-1-1933	N	Subramanian, (S), M.A, Mathematics Department, Annamalai University, Annamalai nagar P O, South India
17-4-1931	R	Sulaiman, (S M.), Hon'ble Sir, Chief Justice, High Court, Allahabad
19-3-1931	R	Taimini, Iqbal Kishen, Ph D, Chemistry Department, Allahabad University, Allahabad
19-3-1931	R	Tewari, Shri Govind, M A., Mathematics Department, Allahabad University, Allahabad
3-4-1933	R	Thompson, (C D), M A. Professor of Economics, Allahabad University.
19-3-1931	R	Toshniwal, (G R.), M Sc, Physics Department, Allahabad University, Allahabad

Date of Election	Alphabetical List of Ordinary Members	
3-4-1934	R	Varma, Rama Shanker, M Sc., Christ Church College, Cawnpore
20-12-1934	R	Varma, (S C.), M Sc, Zoology Department, Allahabad University, Allahabad
9-2-1934	R	Vaugh, Mason, B Sc., Ing, Agricultural Engineer, Allahabad Agricultural Institute, Naini, E I Ry (Allahabad)
19-3-1931	†N*	Vijayaraghavan, (T ), D Phil., Reader, Mathematics Department, Dacca University, Ramna, Dacca
1-1-1930	†R*	Wali Mohammad, Ch, MA, Ph D., I.E.S, Professor of Physics, Lucknow University, Lucknow
15-9 1931	R	Wall, (W G P), M Sc, I.E.S, Associate I.E.E, M R S T, Principal, Training College, Allahabad

*NB* — The Secretaries will be highly obliged if the members will kindly bring to their notice errors, if there be any in their titles, degrees, and addresses

## LIST OF EXCHANGE JOURNALS

Journals	Publishers
1 The Bell System Technical Journal	The American Telephone and Telegraph Coy, New York, (U S A)
2 Proceedings of the Imperial Academy of Japan	The Imperial Academy, Ueno Park, Tokyo
3 Journal of the Franklin Institute	The Franklin Institute of the State of Penn- sylvania, Philadelphia, Penna, (U S A)
4 Bell Telephone System (Technical Publications)	The Bell Laboratories, New York
5 Collected Researches of the National Physical Laboratory	The National Physical Laboratory, Tedding- ton, Middlesex, England
6 Report of the National Physical Laboratory	Ditto
7 The Electrician	The Electrician, Bouverie House, London
8 Proceedings of the Cambridge Philoso- phical Society	The Philosophical Society, Cambridge
9 Proceedings of the Royal Society of Edinburgh	The Royal Society of Edinburgh, Edin- burgh, Scotland
10. Journal and Proceedings of the Asiatic Society of Bengal.	The Asiatic Society of Bengal, Calcutta
11 Indian Journal of Physics	The Indian Association for Cultivation of Science, Calcutta
12 Scientific Notes of the India Meteor- ological Department.	The Director-General of Observatories, Poona 5
13 Memoirs of the India Meteorological Department.	Ditto
14. Journal of the Egyptian Medical Association.	The Egyptian Medical Association, 3 Sharia El-Sanafir, Abdin, Cairo, Egypt
15. Bulletin of the Patna Science College Philosophical Society	The Patna Science College Philosophical Society, Patna.
16. Journal of the Indian Institute of Science	The Indian Institute of Science, Bangalore
17. Current Science .	The Indian Institute of Science, Bangalore
18 Transactions of the Royal Society of Canada.	The Royal Society of Canada, Ottawa
19 Publications of the Kapteyn Astronomical Laboratory	Kapteyn Astronomical Laboratory, Grön- ingen, Holland

	Journals	Publishers
20	Publications of the Dominion Astrophysical Observatory	The Dominion Astrophysical Observatory Victoria, Canada.
21.	Dominion of Canada Natural Research Council	Ditto
22	Proceedings of the Royal Society of Victoria	The Royal Society of Victoria, Melbourne, Australia.
23	Journal and Proceedings of the Royal Society of New South Wales	The Royal Society of New South Wales, Sydney, Australia
24	Transactions and Proceedings of the New Zealand Institute	The New Zealand Institute, Wellington, New Zealand
25.	Publications of the Alleghany Observatory	The Alleghany Observatory of the University of Pittsburgh, Alleghany City, (U S A )
26	Publications of the Observatory of the University of Michigan	The Observatory Library, University of Michigan, Michigan (U S A )
27	Lick Observatory Bulletin.	The Lick Observatory, University of California, Berkeley (U S A )
28	Proceedings of the American Academy of Arts and Sciences	The American Academy of Arts and Sciences, Boston (U S A )
29	Memoirs of the American Academy of Arts and Sciences.	Ditto
30.	Journal of Mathematics and Physics	The Massachusetts Institute of Technology, Cambridge, Mass (U S A )
31	Proceedings of the National Academy of Sciences	The National Academy of Sciences, Washington (U S A )
32	Biographical Memoirs	Ditto.
33	Proceedings of the Academy of Natural Sciences of Philadelphia	The Academy of Natural Sciences, Philadelphia (U S A )
34.	Sinensia .	The Metropolitan Museum of Natural History Academia Sinica, Nanking, China.
35	Proceedings of the American Philosophical Society	The American Philosophical Society, Philadelphia (U. S. A )
36.	American Journal of Science	The American Journal of Science, New Haven (U. S A )
37	Bureau of Standards, Journal of Research	The Director, Deptt of Commerce, Bureau of Standards, Washington (U S A.)
38	Contributions from the Mount Wilson Observatory.	The Mount Wilson Observatory, Pasadena, California (U S. A )
39	Communications (Solar Observatory)	Ditto.
40	Annual Report of the Director of the Mount Wilson Observatory	Ditto



Journals	Publishers
41 Journal of Chemical Physics	The American Institute of Physics, New York, N Y
42 Review of Scientific Instruments	Ditto
43 Transactions of the Astronomical Observatory of Yale University	The Astronomical Observatory of Yale University, New Haven (U S A)
44 Publications in Zoology	The University Library, Exchange Deptt., Berkeley, California (U S A)
45 The Philippine Journal of Science	The Library, Bureau of Science, Manila, P I (U S. A)
46. Anzeiger (Mathematics and Science)	Akademie der Wissenschaften, Vienna, Austria.
47 Almanack	Ditto
48 Anzeiger (Philosophy and History)	Ditto
49 Bulletin de La Classe Des Sciences	The Academie Royale de Belgique, Brussels, Belgium
50 Annales De L'Institute Henri Poincare	The Institute Henri Poincare, Paris (France)
51 Mathematische Und Naturwissenschaftliche Berichte Ana Ungari	The Ungarische Akademie der Wissenschaft, Buda-Pest, Hungary
52 Sitzungsberichte Der Preussischen Akademie	Preussischen Akademie der Wissenschaften, Berlin, Germany
53 Berichte Der Deutschen Chemischen Gesellschaft	Deutsche Chemische Gesellschaft, Berlin, Germany
54 Nachrichten Von der Gesellschaft der Wissenschaften Zu Gottingen Mathematisch-Physikalische Klasse Fachgruppe I. Mathematik	Gesellschaft der Wissenschaften Zu Göttingen, Göttingen, Germany
55. „ II Physik, Astronomie, Geophysik, Technik	Ditto.
56 „ III Chemie, Einschl Physikalische Chemie	Ditto
57 „ IV. Geologie und Mineralogie.	Ditto
58. „ VI. Biologie	Ditto
59. Jahresbericht 1933/34	Ditto
60. Geschäftliche Mitteilungen	Ditto
61. Mathematische Naturwissenschaftliche Klasse.	Bibliothekar, Heidelberger Akademie der Wissenschaften, Heidelberg, Germany.
62 Berichte Der Mathematische Physischen Klasse.	Sächsische Akademie der Wissenschaften, Leipzig. C. I.
63. Abhandlungen Der Mathematisch-Physischen Klasse	Ditto

Journals	Publishers
64. Sitzungsberichte der Mathematisch-Naturwissenschaftlichen	Bayerische Akademie der Wissenschaften Zu München, München, Germany
65. Communications from the Physical Laboratory, Leiden	The Physical Laboratory, Leiden, Holland
66. Supplement, Communications from the Kamerlingh Onnes Laboratory	Ditto.
67. Rendiconti	Rendiconti Del Circolo Matematico Di Palermo, Palermo (Italy).
68. National Research Council of Japan, Report.	The National Research Council of Japan, Tokyo, Japan
69. Japanese Journal of Mathematics	Ditto
70. Japanese Journal of Botany	Ditto
71. Japanese Journal of Physics	Ditto
72. Japanese Journal of Astronomy and Geophysics	Ditto
73. Journal of the Faculty of Science Series I, Mathematics	The Dean of the Faculty of Science, Hokkaido, Imperial University, Sapporo, Japan
74. Collected Work from the Faculty of Science.	The Library of the Faculty of Science, Osaka, Imperial University, Osaka, Japan
75. Proceedings of the Physico-Mathematical Society of Japan	The Physico-Mathematical Society of Japan, Tokyo, Japan
76. Scientific Papers of the Institute of Physical and Chemical Research	Institute of Physical and Chemical Research Komagome, Hongo, Tokyo
77. Journal of Science of the Hiroshima University (Zoology)	The Hiroshima University, Hiroshima, Japan
78. The Keijo Journal of Medicine	The Medical Faculty, Keijo Imperial University, Chosen, Japan
79. Bulletin De L'Academie Des Sciences Mathematiques et Naturelles	The Akademie der Wissenschaft, Leningrad, Soviet-Russia.
80. Journal Du Cycle De Physique et De Chemie.	Academie des Sciences D'Ukraine, Kyiv, Ukraine
81. Journal Du Cycle Mathematique	Ditto.
82. Bulletin de La Classe des Sciences Physiques et Mathematiques	Ditto.
83. Memorias Do Instituto Oswaldo Cruz.	The Instituto Oswaldo Cruz, Brazil (U.S.A.)
84. Physikalische Zeitschrift Der Sowjetunion	Chikovsakaya 16, Kharkov, Soviet-Russia.
85. Geographical and Biological Studies of Anopheles Maculipennis in Sweden.	Kungliga Svenska Vetenskapsakademie, Stockholm, Sweden.

	Journals	Publishers
86	Kungl Fysiografiska Sällskapet Forhandlingar	The Universitet, Lund, Sweden
87.	Uppsala Universitets Årsskrift	Universitet, Uppsala, Sweden
88	Compte Rendu Des Seances De La Societe De Physique et D'Histoire Naturelle.	Societe D'Histoire Naturelle et de Physique, Geneva, Switzerland
89	Comptes Rendus Mensuels Des Seances De La Classe De Medecine	Academie Polonaise Des Sciences et Des Lettres, Cracovie, Poland
90	Comptes Rendus Mensuels Des Seances De La Classe Sciences Mathematiques et Naturelles	Ditto
91	Bulletin International De L'Academie Polonaise Des Sciences et Des Lettres Classe Des Sciences Mathematiques et Naturelles, Serie A	Imprimerie De L'Universite, Cracovie, Poland
92	Ditto Ditto Serie B 1	Ditto
93	Ditto Ditto Serie B 2	Ditto
94.	Bulletin International De L'Academie Polonaise Des Sciences et Des Lettres Classe De Medecine	Ditto
95.	Sprawozdania Z posiedzeń Towarzystwa Naukowego Warszawskiego (History Literatary)	Societa des Sciences et des Lettres de Varsovie, Warsaw, Poland
96.	Ditto (Physiology)	Ditto
97	Ditto (Matematycznofizycznych)	Ditto
98	Ditto (Biologicznych)	Ditto
99	Bureau of Fisheries (Document)	The Commissioner of Fisheries, Washing- ton (USA)
100	Science Bulletin	University of Kansas, Lawrence, Kansas (USA)
101	Mathematisk-Fysiske Meddelelser	Kongelige Danske Videnskaberne Selskab, Copenhagen, Denmark.
102	Biologiske Meddelelser	Ditto
103	Transactions of the Royal Society of South Africa.	The Royal Society of South Africa Uni- versity of Cape-Town, Rondebosch, South Africa.
104.	Comptes-Rendus des Travaux Du Laboratoire Carlsberg	The Carlsberg Laboratorium, Kobenhavn, Valby, Denmark.

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**JOURNAL SUBSCRIBED BY THE ACADEMY OF SCIENCES,  
U.P., DURING THE YEAR 1934.**

**PHYSICS**

1 Die Naturwissenschaften  
22 Jahrgang

Hirschwaldsche Buchhandlung, Berlin,  
N W 7

**LIST OF PAPERS READ BEFORE THE ACADEMY OF SCIENCES,  
U. P., DURING THE PERIOD APRIL, 1934 TO MARCH, 1935**

- 1 "On the Sound absorption coefficient of a few specimen", by Haji G. Moham-  
mad, Physics Department, Allahabad University, Allahabad
- 2 "The Photosynthesis of formaldehyde from 'Nascent Carbon Dioxide' in  
vitro and the importance of respiration in Photosynthesis," by Atina Ram,  
M Sc, Chemistry Department, Allahabad University, Allahabad
- 3 "The Mathematical Theory of a New Relativity", by The Hon'ble Sir Shah  
Mohammad Sulaiman, Kt, M A, LL.D, Chief Justice, High Court,  
Allahabad
- 4 "Continuous deformation of Ruled surfaces", by Prof. Ram Behari Mathur,  
M A, Ph D, Professor of Mathematics, St. Stephen's College, Delhi
- 5 "Observations with an unorthodox Seismograph," by Satyendra Nath Ray,  
M.Sc, 14B, Hewett Road, Lucknow
- 6 "On the direct formation of Bromides and the distance of the closet approach  
of atoms of Bromine," by Binayendra Nath Sen, 15/2 Kali Kundu Lane,  
Howrah (Calcutta)
- 7 "On changes on the Orbit of a particle when disturbed by small tangential  
and normal impulses", by Avadh Behari Lal, M Sc, Ramjas College,  
Delhi
- 8 "The variation of Viscosity during the coagulation of colloidal Aluminium  
hydroxide by potassium chloride solution," by Dr S S Joshi and  
Mr K P N Pannikkar, Chemistry Department, Benares Hindu University,  
Benares
- 9 "Chemical Examination of the Kernels of the seeds of *Cæsalpinia bondu-  
cella*," by Narendranath Ghatak, M Sc, Chemistry Department, Allahabad  
University, Allahabad
- 10 "Ionosphere Height measurement in the United Provinces of Agra and  
Oudh," by G R Toshniwal, and B D Pant, Physics Department, Allaha-  
bad University, Allahabad
- 11 "On a new species of *Catantopus*, Odhner, 1905 from an Indian Fowl *Gallus  
bankiva murghi*," by Har Dayal Srivastava, M Sc, Zoology Department,  
Allahabad University, Allahabad
- 12 "A study of some Organic Reactions at low temperature," by Cromwell  
Osborn Das and S Dutt, Chemistry Department, Allahabad University,  
Allahabad
- 13 "Photolysis of some typical organic compounds in tropical Sunlight," by  
Braj Kishore Malaviya and S. Dutt, Chemistry Department, Allahabad  
University, Allahabad

- 14 "Synthesis of alkaloids derived from cotarnine," by E Venkata Seehacharyulu and S Dutt, Chemistry Department, Allahabad University, Allahabad
- 15 "Notes on a case of unilateral atrophy of testis in the common wall Gecko (*Hemidactylus flaviviridis* Ruppel)," by S. K Dutta, MSc, Zoology Department, Allahabad University, Allahabad
- 16 "A relation between the surface tension and the volume properties of liquids", by M Ramanadham MSc, Pilluka P O, Via Sattenapalli, Guntur District, S I
- 17 "Cytoplasmic inclusions in the Oogenesis of *Anthon sexguttata*," by Murlidhar Lal Srivastava, MSc, Zoology Department, Allahabad University, Allahabad
- 18 "The determination of the potential function of a diatomic molecule in one of its unstable states," by Hrishikesh Trivedi, MSc, Physics Department, Allahabad University, Allahabad
- 19 "A note on Nuclear Spins and artificial Radio-activity," by Dr D S Kothari, Ph D, Physics Department, Delhi University, Delhi
- 20 "A note on uncertainty principle," Dr D S Kothari, Ph D, Physics Department, Delhi University, Delhi
- 21 "A note on the convergence of the conjugate series of a Fourier Series", by Dr B N Prasad, Ph D, DSc., Mathematics Department, Allahabad University, Allahabad
- 22 "Nitrogen fixation in Soils on application of Molasses as manure," by Dr N R Dhar, S K Mukerjee and P K Kar, Chemistry Department, Allahabad University, Allahabad
- 23 "Thevetin-the crystalline glucoside of *Thevetia Nerifolia*," by Narendranath Ghatak, MSc, Chemistry Department, Allahabad University, Allahabad
- 24 "The effect of temperature on the Bacterial Ammonification of Urea," by S P Tandon, MSc, Chemistry Department, Allahabad University, Allahabad
- 25 "New Hemimurids (Trematoda) from Indian Fresh-water Fishes *Clupeaichha*," Part I by Har Dayal Srivastava, MSc, Zoology Department, Allahabad University, Allahabad
- 26 "Note on the absorption spectrum of Carbon Disulphide," by Drs R. K. Asundi and R Samuel, Physics Department, Muslim University, Aligarh, U P
- 27 "Chemical Examination of the roots of *Citrullus Colocynthis* Schrader," by Mr Radha Raman Agarwal and Dr S Dutt, Chemistry Department, Allahabad University, Allahabad
- 28 "On Eight New Species of the Genus *Cycloceolium* Brandes from North Indian Snipes," by M. Hamid Khan, M.Sc, Zoology Department, Allahabad University, Allahabad.

29. "Cytoplasmic inclusions in the Oogenesis of *Scobia quadrupustulatus*,"  
by Murli Dhar Lal Srivastava, MSc, Zoology Department, Allahabad  
University, Allahabad
30. "Contributions to the Digenetic Trematodes of the Microchiroptera of  
Northern India" Part I—New species of the genus *Pycnoporus* Looss  
with a note on *Anchitoma* Looss, by B P Pandt, MSc, Zoology  
Department, Allahabad University, Allahabad
31. "New Parasites of the Genus *Orientophorus*, Nov Gen, Nov Sp (Family-  
Fellodistomidae) from an Indian Fresh-water Fish-*Clupea shaha*," by  
Har Dayal Srivastava, MSc, Zoology Department, Allahabad Univer-  
sity, Allahabad.
32. "The absorption spectra of the vapours of Sulphur monochloride and  
Thionyl chloride," by Hrishikesh Trivedi, MSc, Physics Department,  
Allahabad University, Allahabad
33. "The Mathematical Theory of a new Relativity," (Chapters III, IV, and V,  
by the Hon'ble Sir Shah Muhammad Sulaiman, Kt, MA, LL D, Chief  
Justice, High Court, Allahabad
34. "On determining Sizes of Mangum Terrace Outlets," by A T. Mosher,  
M.A, Allahabad Agricultural Institute, Naini, Et Ry, (Allahabad)
35. "Studies on the Family Heterophyidae Oodhner," Part II --Four New  
Parasites of the Genus *Haplorchis* Looss, 1899, from Indian Fresh-water  
Fishes, by Har Dayal Srivastava, MSc, Zoology Department, Allahabad  
University, Allahabad
36. "Studies on the Family Heterophyidae Oodhner," Part III --Parasites  
belonging to a New Genus from Indian Fresh-water Fishes, by Har  
Dayal Srivastava, MSc, Zoology Department, Allahabad University,  
Allahabad
37. "The Closure property of Three Curves," by S Subramanian, Asst. Lecturer,  
Annammala University, Annamalaiagar P.O, South India.
38. "Physaloptera ochari N Sp from Calotea Versicolor," with a short note on  
Abnormalities of the genus *Physaloptera*, by M B Mirza, Ph.D., Zoologi-  
cal Laboratories, Muslim University, Aligarh
39. "On a property of the Parabolic Cylinder Functions," by S C Mitter, 35  
Hathkola Road, P O Wari, Dacca
40. "Some Rare Polyporaceae of the Central Provinces," by P R Bhagwagar,  
M.Sc., Botany Department, Allahabad University, Allahabad
41. "On the determination of absorption coefficients of sound for different  
materials," by Laxmi Prasad Varma, M.Sc., Physics Department,  
Allahabad University, Allahabad.
42. "On Sulaiman's Physical Theory of Gravitation I" by Satyendra Ray, M.Sc.,  
14B Hewett Road, Lucknow

*Financial Statement - From April, 1934 to 31st March, 1935*

Receipts		Expenditure	
	Rs a p		Rs a p
Bank Balance on 1st April, 1934	2,249 10 9	Establishment	793 8 0
U P Government Grant (Non-recurring)	2 000 0 0	Honorarium to Assistant Editor	150 0 0
Allahabad University Grant (Non-recurring)	500 0 0	Contingency (including printing, postage stamps and stationery, etc.)	455 4 0
Donation	400 0 0	Printing of Proceedings 1934-35	2,767 13 0
<i>Membership Fee :-</i>		Binding of Journals	84 5 0
Resident membership fee for 1931	15 0 0	Furniture	98 0 0
Resident membership fee for 1932	75 0 0	Bank charges on outstation cheques	3 4 0
Resident membership fee for 1933	240 0 0	Cycle	60 0 0
Resident membership fee for 1934	540 0 0	Bank Balance on 31st March, 1935	1,466 0 0
Resident membership fee for 1935	105 0 0	Building Fund	Rs 400 5 9
Part payment of subscription for 1935	6 0 0	Balance	1,866 5 9
Non-resident membership fee for 1932	10 0 0		
Non-resident membership fee for 1933	20 0 0		
Non-resident membership fee for 1934	70 0 0		
Non-resident membership fee for 1935	40 0 0		
Associate for 1934	10 0 0		
	1 131 0 0		
<b>Total Rs</b>	<b>6,280 10 9</b>	<b>Total Rs.</b>	<b>6,280 10 9</b>

(Sd) H R MEHRA, Ph D  
Hony Treasurer,  
The Academy of Sciences, U P



**Message from His Excellency Sir Harry Haig,  
The Patron of the Academy**

*Governor's Camp,  
United Provinces,  
February 28, 1935*

*The Academy of Sciences of the United Provinces is holding its Fourth Annual Meeting and we may hope that it has now firmly established its position. I am sure that the Academy is doing important work for the advancement of Science in India, and I trust that its success will continue uninterrupted.*

*(Sd) Harry Haig,  
Governor,  
United Provinces*

**Message from the Hon'ble Sir J P Srivastava,  
The Minister of Education, U P**

*Lucknow,  
February 25, 1935*

*Dear Mr. Banerji,*

*Thanks for your letter of February 18, asking me to send you a message for the Fourth Annual Meeting of the Academy of Sciences to be held at Allahabad on the 27th February. I am very sorry that it would not be possible for me to be present at this meeting, but I authorise you to tell the meeting that the Academy has my very best wishes. It is, I think, fulfilling a very useful purpose in promoting scientific research in this province and elsewhere and it is the duty of all well-wishers of the country to extend to it a helping hand. Great credit is due to the band of workers to whose enthusiasm the Academy owes its inception and existence. The Government has recognised the Academy by including in the annual schedules a grant of Rs. 2,000 for the Academy.*

*Yours sincerely,  
(Sd) J P Srivastava*

*Prof. A. C. Banerji,  
Allahabad University,  
Allahabad*

**PRESIDENT'S ADDRESS**  
**ADDRESS OF THE PRESIDENT,**  
**PROFESSOR K N BAHL,**  
**AT THE ANNIVERSARY MEETING**

*Held on February 27, 1936*

DR FERMOR, FELLOWS AND MEMBERS OF THE ACADEMY, LADIES AND GENTLEMEN,

My very first duty as President of the U P. Academy of Sciences is to offer a very hearty welcome to Dr L. L. Fermor, F R S, for having taken the trouble of coming over to Allahabad to participate in our fourth annual meeting. Extremely busy as he is with his duties as Director of the Geological Survey of India, it is very kind of him to have come over to encourage us with his presence and advice.

The secretaries have given us an account of the working of the Academy during the year and I hope you will all agree with me that we have made the best use of our limited resources and have done good and useful work. I wish to record my very best thanks to Dr. M N Saha who has given of his best to the Academy and has all along zealously guarded its interests. My best thanks are also due to our energetic secretaries, Professors Banerji and Macmahon, for their cordial co-operation and assistance.

The most notable event in the history of scientific activity in India during the last year has been the inauguration of the National Institute of Sciences. Our Academy had to consider its position with regard to this all-India institution and we decided wholeheartedly to support the idea underlying the establishment of the National Institute, as it did not interfere with our individuality or independence. Now that the National Institute has been established, we have offered our cordial co-operation and it is a happy augury for the future good relations between the National Institute of Sciences and ourselves that we have the President of the Institute as our distinguished guest this afternoon.

As this is the last time I shall preside over the Academy, I wish to introduce to you my successor, Dr N R. Dhar, D Sc, I E S, Professor of Chemistry in the University of Allahabad. He is a distinguished educationist and a chemist of great eminence. He has been associated with the Academy from its very inception and I have no doubt that he will infuse fresh life into the working of the Academy.

Last year, I spoke on the "Present Position of Darwinism," but this year I have selected a more restricted subject, namely, the "Evolution from Fish to Man" and I shall begin by stating the accepted creed of the biologist that man is merely one amongst the great hosts of animal life on this globe, he is part of an unbroken stream of life. The stream of life, that flows through our human generations and that we call man, was once a fish and it has been transformed into our present selves in about 300 million years <sup>1</sup>

During these 300 million years, Nature has made many an experiment and many an invention, of which I shall select only a few and trace the human evolution through successive stages from our fish-like ancestors. Take the example of a motor-car or better that of an aeroplane—the remarkable accomplishment of the flight from London to Melbourne in less than 71 hours is still fresh in our minds—both these machines represent the high-water mark of human invention and design; the working of both of them is based on one important basic invention, namely, that of the *petrol engine*. Otto's gas-engine led to the paraffin oil engine and this in turn led to the petrol-engine of Gottlieb Daimler, who in 1887 used his petrol engine to drive a car on the road. The world has discovered in Daimler's petrol engine an appliance such as it had never possessed before, it has given man a new mobility which has changed his notions of distance and time. In due course, the petrol engine has achieved the conquest of the air <sup>2</sup>

The human body is vastly more complex than any motor-car or air-ship, both in its locomotor machinery and in its instruments of precision and more than one basic invention had to be made by Nature to accomplish the evolution of man <sup>3</sup>. Let us consider the locomotor machinery first and start from a shark-like ancestor. Fig 1 shows the body of the common shark of the Indian seas with a part of the skin removed to show the arrangement of the zig-zag muscle-segments <sup>4</sup>. Each of these muscle-segments is made up of a large number of striped muscle-



Fig. 1—Scoliodon

<sup>1</sup> Wells, Huxley and Wells,— *The Science of Life*, 1931

<sup>2</sup> Ewing, A.—"Power," *Nature*, Vol. 128, 1931

<sup>3</sup> Gregory, W. K.—*Basic Patterns in Evolution*, 1930.

<sup>4</sup> Thittayampalam, R. M.—"Scoliodon," *J. Z. M.*, 1928.

fibres placed horizontally. The next figure shows a few of these muscle-fibres as seen under the microscope. The muscle-fibre is really the unit



Fig 2 — Striped muscle-fibres  
showing stripes

of the locomotor apparatus of all vertebrates and it is by combinations of these zig-zag muscle-stripes of the shark that the complex musculature of the body and limbs of man is built up. Many of the Invertebrates have already attained to this stage and it is from them that the vertebrates have inherited their locomotor machinery. The physiology of the contraction of the muscle-fibre has been studied intensively during recent years and we now know that we can compare, as Sir Arthur Keith<sup>1</sup> has done, a muscle-fibre with a tiny gas-engine which utilises oxygen in its recovery stage after performing the work of shortening the muscle-fibre. Each muscle-fibre of the shark is fastened at each end to a connective tissue partition. Delicate nerve-fibres run to each of these red muscles and the contraction is so timed that a wave of contraction runs along one side of the body from the head to the tail. But soon after the first wave starts, a second begins on the opposite side, then a third on the same side and so on. It is by means of these backwardly passing waves that the fish drives its body forwards through water.

The striped or voluntary muscle-fibre is, in fact, the basic invention of the locomotor machinery of all vertebrates,<sup>2</sup> like the petrol engine of the motor-car or the aeroplane. Further, like the petrol engine it was preceded by different and comparatively simpler machines of the smooth muscle-fibre and the cardiac muscle-fibre. Normally, the striped muscle-fibre contracts with great rapidity and only upon stimulation by a nerve, while the smooth muscle, being less differentiated, appears to have retained more of its power of spontaneous contraction.

This simple form of zig-zags arranged at length uniformly throughout the body serves only for an animal like the primitive lancelet or *Amphioxus* or for a fish like the eel, the exact mode of locomotion of which has recently been described so admirably by Gray.<sup>3</sup> In most

<sup>1</sup> Sir Arthur Keith—*Engines of the Human Body*, 1926.

<sup>2</sup> Gregory, W. K.—*Banc Patents in Evolution*, 1930.

<sup>3</sup> Gray, J.—*Studies in Animal Locomotion*, (Ed.), *Journ. Exper. Biol.*, 10, 1933,

modern fishes, these zig-zags adhere and unite into groups producing what we might call compound muscles. Structures like the tail and the pectoral and pelvic fins cannot be adequately worked by simple waves produced by muscle-segments arranged lengthwise. We thus get to the second stage, that of the grouping of simple muscle-segments, producing, so to speak, a high-



Fig 3 — *Amphioxus*, ventral and side views

powered 8-cylinder engine instead of the original one-cylinder engine of Daimler. Large powerful muscles of arms and legs in man or the flight-muscles in a bird afford the best examples of this large-scale grouping of muscle-fibres.

A word about the general shape of the fish. At a very early period, the vertebrate body as a whole had been modelled into a "stream-line"



Fig 4 — Devonian shark *Cladodus*

form, a feature which is now becoming a vogue amongst motor-cars. Most fishes have a blunt rounded head and flowing contours passing behind into the rudder-like tail. A fish moving in water will need keels and rudders to steady and direct its forward progress and these were present in the most ancient and primitive known fishes, e.g.,

the sharks of the Devonian period, as merely stiff folds of skin, called the fin-folds. These folds were probably just warped by the zig-zag muscles of the body and had the minimum of independent movement of their own, but in higher fishes, the bony rods supporting these fins fused together and formed the beginnings of the complex shoulder-girdle and fore-limbs and the hip-girdle and hind-limbs of land vertebrates. Usually the simple dorsal and anal fins retain their more primitive condition, while the pectoral and pelvic fins become limb-like, the pelvic becoming paddle-like and the pectoral acquiring a narrow wrist-like base capable of elaborate movements. As the keel-like fin-folds acquired a skeleton, there was an extension of the segmental muscles and corresponding nerves towards them to direct their movements; that

this actually happened is strongly supported by the fact that during the embryonic development of all higher vertebrates, including man, the fore- and hind-limbs develop from bud-like outgrowths involving folds of skin from the body-wall and an extension of the segmental muscles and nerves from the flanks

We have so far been dealing with fishes and their progression in water. The next great step was the passage of our ancestors from water to land. This must have involved a series of experiments and inventions until the four-footed terrestrial vertebrate was evolved. We are agreed that land vertebrates have arisen from fish-like ancestors. Two most important changes must have occurred in the passage from water to land—(1) the origin of limbs and (2) the origin of lungs. Lungs and legs, in fact, are the characteristic marks of a land vertebrate. The problem, therefore, is to explain how the walking four-footed animal evolved from the swimming fish, such as we have on the screen now, without any sudden alteration of the structure and function of its parts, by a series of gradual steps, each of advantage in the struggle for existence.<sup>1</sup>

We have already seen that a typical fish swims principally by the undulations of its body and tail and is helped by its paired fins, which are stiff folds of its body-wall, each with an internal skeleton movably articulated at its base to the supporting limb-girdle. The walking limbs of the earliest land-animal, which by common



Fig 5 — *Cephalaspis*.

consent must have been an Amphibian, consist of paired pectoral and pelvic projecting limbs built essentially on the same plan, and each subdivided by movable articulations into three regions, the outermost bearing typically five digits, the limb being therefore called a pentadactyle limb

Two questions immediately present themselves:—(1) From what kind of fish could land-animals have evolved? What group of fish is sufficiently advanced and at the same time sufficiently primitive to give rise to land-forms? and (2) What was the earliest land-form like? As regards the first question, it is now agreed that

<sup>1</sup> Goodrich, R.S.—The Origin of Land Vertebrates, *Nature*, 1924.

lobe-finned fishes and the Dipnoi, as shown in Fig 6., formed the starting point. Both these types of fishes are fresh-water forms and it is probable that the transition from aquatic to terrestrial life took place in streams and pools, in fresh-water rather than in sea, because it is in fresh-water that access to land was easy. Dipnoi and possibly the Osteolepids alone amongst the fishes have pectoral and pelvic fins of the same structure—sufficiently alike to have given rise to paired walking limbs. In other fishes, the pelvic fins are too much reduced or specialised, too unlike the pectorals, to have developed into the hind-limbs of a land vertebrate. Further, the Dipnoi



Fig 6—*Ceratodus*, *Dipterus* and *Osteolepis*.



Fig. 7—Pectoral girdles and appendages

alone of all fishes show an additional ascending process separating the profundus from the maxillary branch of the 5th nerve, besides basal and otic processes, by means of which the hinder region of the palatoquadrate bar is firmly attached to the skull<sup>1</sup>

Having settled the type of the progenitor of the land-forms we turn to the second question—Which of the Amphibia came first? It is well known that all the modern forms of the Amphibia—frogs, newts, salamanders, etc.,—are highly specialised, although they retain a few essentially primitive characters, *s.g.*, they still lay their eggs in water and pass through a larval stage provided with gills. For the earliest Amphibian we have to go to the ancient and primitive Stegocephalians (Labyrinthodontia) which flourished in the Carboniferous and Permian times. They

<sup>1</sup> Goodrich, R.S.—The Origin of Land Vertebrates, *Nature*, 1924  
F. 5

formed a large assemblage, and, according to Professor T.H. Huxley, some of them "pottered with much belly and little leg, like Falstaff in his old age, among the coal forests"<sup>1</sup>

The question of the substitution of aerial for aquatic respiration in land vertebrates need not detain us long. Even the living Dipnoi, while retaining gills and gill-slits, have become adapted to survival in rivers liable to be dried up or to become foul in dry weather by acquiring a nasal passage from external to internal nostril (by closure of the nasal groove) and a lung for breathing air taken in at the surface. Goette and Spengel have suggested that the lung was probably derived from a posterior pair of gill-pouches which failed to open to the exterior, retained an ample blood-supply and joined together ventrally. To this day, in land-forms the lung first appears as a pair of diverticula of the pharynx, thus, if we derive the lung from the posterior pair of gill-pouches, it would have no sudden origin and would fit in with the series of gradual steps leading from an aquatic to a terrestrial existence.<sup>2</sup>



Fig. 8.—Transition from water to land

The first step towards lung had been taken when the bony fishes developed an air-bladder, but the actual steps by which

the fin was changed into a leg have not been discovered yet; a lucky geologist may find traces of these steps in the Devonian era at some future date.<sup>3</sup>

The next step in the evolution was the transition from an amphibian to a reptile. This transition involved at least two new basic inventions: (1) a tough dry skin which was not subject to desiccation and (2) a shelled drought-resisting egg which contained not only plenty of food-material but also a little pond inside the amnion that enabled the embryo to do away altogether with the need of resorting to water.<sup>3</sup> Geologists tell us that towards the close of the Carboniferous period, the swamps and the steaming forests began to disappear and in their place dry land arose and set a premium on the development of full adaptation to life on land. Just as necessities of war have led to a quick development of

<sup>1</sup> Wells, Huxley and Wells—*The Science of Life*, 1931.

<sup>2</sup> Goodrich, R. S.—*Studies in the Structure and Development of Vertebrates*, 1930.

<sup>3</sup> Wells, Huxley and Wells—*The Science of Life*, 1931.



the aeroplane, similarly drought in the first instance and the disappearance of lakes and lagoons later led to the full emergence of land vertebrates, which at once took to feeding on the luxurious vegetation existing on land at the time.<sup>1</sup>

In water, the skin was moist and thin but on land you need a tough skin like that of a politician, a politician has to be resistant towards abuse and misrepresentation, a game which animals do not indulge in; an animal's skin has to be resistant to drought.

The primitive land-vertebrate (Stegocephalian) had its body suspended between the shoulder-girdle and the hip-girdle by muscular straps

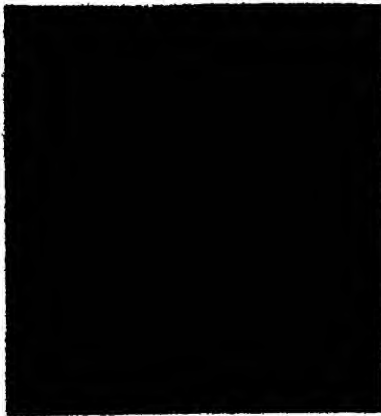


Fig. 9.—Evolution of limbs from fins



Fig. 10.—Limbs of a Cotylosaur and Opossum

and the whole structure rested in turn on the limbs which were widely bent outwards in order to check any undue tendency for the body to fall over on its side. Gradually the body was lifted completely off the ground and the animal, instead of using its zig-zag muscles of flank, now relied for its propulsion exclusively upon the extension of its limbs. From the very first, the limbs acted as jointed compound levers which were alternately folded up and extended in the same way as we extend and fold up our own legs in walking. Once the primitive land-living type of organisation had been achieved, the subsequent changes in the skeleton from the earliest reptile to man introduced no major changes in the basic plan, however great were the advances in the ways of living and in the mental life.<sup>2</sup>

<sup>1</sup> Wells, Huxley and Wells—*The Science of Life*, 1931.

<sup>2</sup> Gregory, W. E.—*Twenty-five Stages of Vertebrate Evolution*, Science, 1933.

The most primitive reptiles were the Cotylosaurs, as shown in the slide before us, survivors of an ancient stock from which diverged birds and



Fig. 11.—Cotylosaur, Theriodont, (Opossum

mammals and ourselves. The Reptiles flourished in abundance in the Miocene age which is styled the Golden Age of Reptiles, during which they reached their greatest elaboration and their greatest size. We are not directly concerned at present with giant-forms like

*Brontosaurus* and *Diplodocus* but shall pass on to humbler but all the same most remarkable reptiles—the Theriodonts, so called because they were the first vertebrates to show in a well-developed manner the division of the teeth into different groups—molars, canines and incisors, so characteristic of mammals



Fig. 12.—A Theriodont

In these mammals the body was raised clearly off the ground, the feet were brought under the body and the elbows and knees were drawn in at the sides. They were probably insect-eating forms with low types of brain and a primitive type of skeleton. During the later Miocene and early Eocene periods, some of these smaller mammals began the habit of climbing trees—a habit which is deeply impressed upon the skeleton of monkeys and apes—a group to which man belongs. So long as progression was limited to the ground, the task of propelling the body with movable legs was comparatively simple. But in proportion as the early mammals succeeded in climbing trees and in leaping and running among the branches, the problem became more and more complex, especially in the devices necessary for more accurate and speedy adjustments in balancing



Fig. 13.—Gibbon.

Sir Arthur Keith, who has made far-reaching investigations on the anatomy of man-like apes, was astonished to find that the gibbon had

already solved the problem of bipedal upright progression to such an extent that in great many ways, its visceral arrangements were



Fig. 14 — Apes and Man.

fundamentally identical with those seen in man.<sup>1</sup> Making the arms free for climbing purposes was a great step in the evolution of man—a very important invention, so much so that Sir Arthur Keith has invented a special term "*brachiation*" to describe progression by means of arms

*brachiation*" to describe progression by means of arms

It is this brachiation<sup>2</sup> that has led to upright posture, the great distinguishing feature of man. In man, the hand is chiefly used for

carrying and manipulating objects while in the apes it is still very largely used as an organ of locomotion. But the interesting fact remains that human hand still bears in its musculature the impress of the climbing habit of his ancestors. The slide before us shows the musculature of the hand of man side by side with that of an ape and we see the close correspondence



Fig. 15 — Ape-hand and Human hand

between the two. Similar is the correspondence in the musculature of the foot. Biologists hold that this habit of brachiation led to the close connection between the pelvis and the legs and that led to the upright posture of man and this in turn has led to our progressive evolution in the struggle for existence. Clearness of eye, swiftness and sureness of foot on the one hand, memory, fore-thought and inventiveness on the other, are the results, direct and indirect, of our comparative independence from environmental conditions which began with our ancestors taking

<sup>1</sup> Gregory W. K.—'The Upright Posture of Man,' *Proc. Amer. Phil. Soc.*, 1928.

<sup>2</sup> Gregory W. K.—The Origin of Man from a Brachiation Anthropoid Stock, *Science*, 1930.

to a climbing habit of life. Constant temperature and embryonic existence within the mother, conditions which we share with other mammals,

provided delicate adjustments which in their turn enabled an elaborate and delicate brain-machinery to be developed.

The series of forms which the stream of life has passed through in its evolution to man is shown in the accompanying figure



Fig 16 —Series of skeletons from fish to man

This is the evolutionary record preserved in bones and bony fossils of our ancestral history. A great deal of this record is a record of struggle and destruction of rival forms. It is only in higher mammals and in apes that the family and the horde came into existence, then alone unselfish interest in others began to operate and led to the unselfishness of mothers, the devotion of fathers and the generosity and disinterestedness of friends. *Homo sapiens* is really a patch-work of both good and evil. But our past history makes us very optimistic about our future and in consideration of our cosmopolitan distribution, mankind should be a "good risk" for survival for an indefinite period.

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ADDRESS BY DR. SIR LEWIS LEIGH FERMOR, Kt, OBE,  
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DR. BAHL, LADIES AND GENTLEMEN,

I am glad to be present at the annual meeting of the Academy of Sciences of the United Provinces, and I am highly honoured at being asked to preside. In this I feel, however, that I am usurping the privilege of the President of your Academy and, in fact, I expostulated with your Honorary Secretary to this effect. He assured me, however, that it was the custom of the Academy that some one other than the President should be in the Chair on this occasion, and on referring to your Bulletins I find that in fact His Excellency Sir Malcolm Hailey, the Hon'ble Mr J P Srivastava, and the Hon'ble Sir Shah Mohammad Sulaiman respectively presided at your previous three annual meetings.

What I view with special disfavour is the idea that the Chairman of the day should be expected to deliver an address in addition to that given by the President of your Academy. I should have taken comfort from the short addresses given on the first two occasions, were it not for the very interesting and lengthy address given by Sir Mohammad Sulaiman last year.

**The National Institute of Sciences of India**

It seems desirable to say a few words about the new scientific organisation in India founded this January, namely, the National Institute of Sciences of India, especially as the success of this organisation will depend partly upon the extent to which the three bodies of academy rank in India, of which yours is one, enter into the scheme of co-operation. As you know, the National Institute of Sciences has been founded as a body of limited Fellowship,—limited not as to the total number of Fellows, but by the number to be elected annually. In this National Institute it is our hope gradually to enroll all the senior scientists of India, including all those whose work is of outstanding merit. The aims and objects of this new organisation have already been outlined by me in my inaugural

address to the National Institute, but I wish to emphasize here that it is not the purpose of this National Institute to compete with and undermine the activities of the three bodies of Academy rank in existence in India, namely, in order of formation, the Asiatic Society of Bengal, your Academy, and the Indian Academy of Sciences founded at Bangalore. These three bodies, all have all-India aspirations, but in virtue of their geographical distribution, they may be regarded as, for practical purposes, effecting a convenient geographical partition of India with suitable spheres of influence. These three Academies are available to satisfy the continuous needs of the scientists of all sciences in various parts of India for philosophers' gardens where men may meet and discuss their views and problems, particularly their problems of common interest, as distinct from the specialist matters more suitable for the specialist societies for particular sciences.

The chief task of the National Institute will be to act as an organising body for scientific effort in India and as a co-ordinating body, in the first place to the labours of the Academies. For, with the Academies, it represents the need for bodies of a general nature to counteract the growing trend towards specialisation in science in India, as in all countries. At present, as the National Institute is but newly founded, we are cautiously treading our way, and the fellows of the National Institute must not expect too much during the first year, but I anticipate that it will soon be found that there are many problems and tasks that can suitably be entrusted to the National Institute, with the expectation that the Institute, with the brains of the whole of scientific India at its disposal, will be able to arrange to the best advantage for the solution of the problem or the organisation of the task.

Although the formation of the National Institute must be regarded as a natural necessity for the purpose of counter-acting to some extent the trend towards specialisation, yet there is still a need and a place for specialist societies, and none of them need view with any apprehension the foundation of our co-ordinating body, instead, they will find, in the not distant future, that we shall be calling upon not only for their co-operation.

I am sure, however, that you do not wish to hear only about the new organisation, but would instead like to have a few words concerning my own special branch of knowledge, namely, geology.

In 1934, Behar and Nepal were, as you know, shaken by a very serious earthquake, namely, the Great Earthquake of the 15th of January, 1934. An earthquake, although it must originate in a definite spot, does

not confine its effect to its origin, for it operates, as you know, by the propagation of earth waves of various types. The occurrence of these waves is recorded by seismographs often upon great distances from the source, whilst when the shock is sufficiently severe the waves are also perceived or felt by man though to a much smaller distance from the source. It is calculated that the earthquake of last January was strong enough to be felt by man over 1,900,000 square miles of country, whilst it was recorded by the seismographs of the whole world. Although the United Provinces was not the worst sufferer, yet this province was close enough to the source for serious effects to be produced in many of your towns. You are, therefore, practically interested in the cause of earthquakes, and a few words from me on this point may prove of interest.

It is generally agreed that earthquake shocks are due to movements within the earth's crust. Some shocks can be shown to be directly related to the dislocations in the earth's crust that geologists term 'faults' and, in fact, in some earthquakes small faults are seen to be produced visibly at the surface as a result of the earthquake, as for example, in the great earthquake of Assam in 1897. In cases where earthquakes can be directly ascribed to movements along faults, it is safe to say that they represent the sudden relief of strains that have been accumulating for some time in regions subjected to tectonic stress, the strength of the earth's crust having permitted the accumulation of strains which otherwise would have been relieved as rapidly as produced.

### **Gangetic Alluvium Underloaded**

The epicentral tract of the great earthquake of last January was, however, in a tract where no consolidated rocks appear at the surface, for it was in the middle of the Gangetic alluvium, which masks completely the nature and structure of the underlying more consolidated rocks. We can surmise what these rocks may have been, but we do not know if we are right, for no bore holes have ever penetrated the Gangetic alluvium except near its edges, and there are reasons for supposing that this alluvium is many thousands of feet thick. In the absence of knowledge it is, however, possible to speculate that, as is known in many other cases, this great earthquake was due to some fault movement in the more consolidated rocks below the alluvium representing the partial relief of accumulated strains. That this may possibly be the truth will be realised when I mention that according to the geodetic observations of the Survey of India, this portion of the Gangetic alluvium suffers from a deficiency of gravity, or is underloaded.

It is possible by a study of the records of seismographs at various distances from the focus to deduce roughly the depth of the focus of an earthquake, and it is found that whilst many of the earthquakes of the world have originated at foci situated close to or within a few miles of the surface, some earthquakes have originated at much greater depths, — at depths so great indeed that it seems probable that the rocks there must be, on account of high temperatures and pressures, in a more plastic condition than those nearer the surface, and probably unable, therefore, to accumulate strains due to tectonic earth movements. For these deeper earthquakes, therefore, it seems necessary to look for a different type of cause, than the relief of tectonic strain.

### Garnets

Such a cause I was able to suggest many years ago—the suggested cause being a rapid change in volume of deep-seated rocks due to the passage of one mineral phase to another. This leads me to what appears to be an incongruous change from discussing earthquakes to discussing garnets. The mineral garnet is, as some of you know, one of the most condensed minerals with which the geologist has to deal. It is complex silicate of high density belonging to the cubic system, and in a paper published many years ago entitled "Garnet as a Geological Barometer"\*, I indicated crudely the extent to which the presence of garnet in rocks might be taken as an indication of the application of pressure, and I amused myself considering what would happen to various rocks if they were subjected to pressures and temperatures high enough to cause the maximum production of garnet. It is interesting first to consider the common rock basalt, which almost all geologists now agree forms a continuous shell of the earth below the more acid rocks of the crust. It is this shell which, when tapped, gives rise to the vast basaltic lava flows that have overwhelmed the surface of the earth in so many countries. In India we have the largest of all these manifestations, namely, the Deccan Trap, covering some 200,000 square miles of Western India. These lavas reached the surface not through volcanoes of the central type, but through fissures coming from unknown depths, and now represented at the surface by dykes of basalt and dolerite: we must picture the molten rock as having come from 10 or 20 miles below, as the result of some release of pressure. Normally pressures at

\* 'Preliminary Note on Garnet as a Geological Barometer and on an Infra-Plutonic Zone in the Earth's Crust,' *Rec., Geol. Surv. Ind.*, XLIII, pp 41-47, (1913).



such depths are so great that it appeared incredible that a rock of basaltic composition could at such a depth below the surface exist actually as basalt, that is as a rock made of labradorite feldspar, augite, and iron-ore. In fact, my suggestion was that at that depth the rock of basaltic composition would be present in the form of eclogite which is a highly garnetiferous rock of similar chemical composition to basalt, but composed normally of pyroxene, garnet, and rutile, and consequently of much higher specific gravity. Calculations show that the eclogites and related garnetiferous rocks occupy from 10 to 20 per cent less volume than the corresponding basalt or gabbro, so that whereas the density of basalt is 2.9 to 3.0, the density of eclogite is about 3.4 to 3.5.

### Conditions Below Earth's Crust

General considerations indicate that the reactions by which garnets would be formed from the minerals of basalt must be endo-thermic ones. This means that the conditions that would cause basalt or gabbro to pass into eclogite, should be conditions requiring decrease of volume and absorption of heat. These are exactly the conditions that must prevail at considerable depths in the earth's crust, and it seems philosophically sound, therefore, to suppose that the lower portion of the basaltic shell of the earth's crust must be in eclogitic phase, and further that there must be a zone where the two rocks meet, in which passages from basalt to eclogite and the reverse must be taking place periodically according to change of pressure, and that, in fact, in this layer we have a cushion by means of which isostatic adjustments of the earth's crust can be effected, the passage of eclogite to basalt or gabbro leading to the elevation of the surface and the passage of basalt or gabbro to eclogite to a sinking of the surface. Once one accepts the philosophic necessity of the presence of the shell of eclogite (my infraplutonic zone)—a hypothesis which has not yet been accepted by all geologists, as some prefer to think in terms of peridotite rather than eclogite—it is possible to put forward explanations of isostasy, vulcanicity and earthquakes, and even of the formation of chondritic meteorites. These are all fascinating branches of this speculation, and ones upon which I have expressed preliminary views elsewhere, but the one which concerns us just now in the possible explanation of deep-seated earthquakes. Deep-seated earthquakes appear to require sudden increases of volume at some depth below the surface, and the only possible way in which this increase of volume can be provided appears to be by some rapid change of mineral phase. The question is whether the passage of eclogite to basalt can

provide this explanation. The possibility of this explanation being correct depends first upon the possibility of there really being an eclogitic shell, and this depends upon the possibility of the stability of the garnet, which is a somewhat easily fusible mineral, at the high temperatures that prevail at the depths in question. We have, however, ocular evidence of the ability of eclogite to exist at considerable depths in the form of the blocks of eclogites contained in the diamond pipes of Kimberley in South Africa, and allowing for the fact that the melting point of garnet probably increases with pressure, it seems likely that garnet and consequently eclogite can persist at such considerable depths. If this be accepted then it is obvious that there must be places where the garnet is kept solid in spite of the high temperature only by the prevailing pressures, and that with any slight release of pressure the garnet must immediately become unstable. The question is whether such instability developed over a large mass of rocks could produce explosive results competent to cause an earthquake shock.

### A Talisman

Having made this suggestion, which is really reviving a suggestion of the past, I prefer to leave the subject, as I have already encroached upon your time. But this I will say, this garnet hypothesis may be regarded as an illustration of a possibility. If, in fact, garnets are unable to exist at the depths in question, nevertheless the possibility of explaining deep-seated earthquakes, by sudden changes of mineral phase still exists, and it is the principle rather than the details that is important. Whilst on this subject, however, I must express a slight apology in that having launched on these interesting speculations concerning earthquakes, vulcanicity, isostasy and meteorites so long ago as 1910, I have not developed the subject further. The reason, of course, is that the systematic field work of a Geological Survey geologist, coupled with administrative work when at headquarters, makes it difficult to sufficient attention to theoretical speculations. During the years that have elapsed I have, however, kept my eyes open, and nothing that has been published on these four subjects appears to me to render my early speculations improbable, and to me, through all these years in the jungle, the mineral garnet with its fascinating possibility has always been to me a talisman helping to throw light upon problems connected with the structure of the earth's crust.

## **VOTE OF THANKS TO PROF. K. N. BAHL AND PROF. A. C. BANERJI**

In proposing the vote of thanks to Prof. K. N. Bahl and Prof. A. C. Banerji, Dr. P. L. Srivastava spoke as follows —

On behalf of the U. P. Academy of Sciences, I consider it a privilege to rise to propose a hearty vote of thanks to Dr. Bahl, our retiring President, and Prof. A. C. Banerji, our retiring Secretary. Dr. Bahl has been associated with our Academy since its very inception. In fact he is one of the founders of the Academy, and it was in the fitness of things that he succeeded Dr. Saha who was our first President. During the two years that Dr. Bahl was our President, he guided the activities of the Academy with great tact and resourcefulness. He took a keen interest in its affairs and came to Allahabad on several occasions to preside over our meetings at considerable sacrifice. The Academy cannot be sufficiently grateful to him for all that.

As regards Prof. Banerji, it is impossible for me to express the gratitude of the Academy to him in adequate words. To Prof. Banerji goes the credit of doing the entire spade work and of keeping the Academy in working order for four long years. He gave a lot of his precious time and energy to the work of the Academy. But for him the Academy would not have achieved the success that it has done. If Dr. Saha has been the brain of the Academy, Prof. Banerji has been its very soul!

Gentlemen, it is with the greatest pleasure that I propose a hearty vote of thanks to Profs. Bahl and Banerji.

Dr. Tarachand seconded the above vote of thanks.

## **VOTE OF THANKS TO Dr. SIR L. L. FERMOR**

In proposing a vote of thanks to Dr. L. L. Fermor, Prof. M. N. Saha said :—

It has indeed been very kind of Dr. Fermor to have agreed to come at such a short notice to Allahabad and preside over our Annual function. Dr. Fermor came to India nearly 33 years ago, as an officer in the Geological Survey of India of which he is the Director now. His contribution to the Science of Geology is recognised all over the world, and as mark of recognition of his eminence as a Geologist, the Royal Society has recently elected him as one of its fellows. His connection with

Indian Scientific men has been very intimate and he has regularly attended the meetings of the Indian Science Congress, and was its General President in 1933 at Patna

My personal acquaintance with Dr. Fermor dates from the year 1934, when I met him for the first time at the Bombay Science Congress and fate drew us together in the work of organisation of the National Academy of Sciences for the whole of India, he as president and myself as secretary of Academy Committee appointed by the Indian Science Congress. I need hardly repeat here the story of fight and struggle we had to go through in bringing the National Institute of Sciences for India, which is to act as National Academy, into existence Suffice it to say that we found that the land mass we call India, not only consists of geological formations widely varying in chemical composition and physical characteristics, but we found that ethnological India was also composed of different stratas widely differing in their outlook, ideals and objectives To evolve an order out of a chaos of divergent interests appeared at times almost an impossible task, but our distinguished friend rose equal to the occasion and probably his knowledge of geology was responsible for this unique achievement. The National Institute of Sciences, founded at Calcutta in January, 1935, is a striking monument to his patience, forbearance and tact.

To-day the U P. Academy of Sciences celebrates its fifth anniversary Let us hope that it will cooperate with the National Institute in bringing about unity in the ranks of Indian Scientists and promoting the knowledge of science in this country

We are very grateful to our friend for having come here and presided over our annual gathering I invite you all in according him a hearty welcome and in proposing a hearty vote of thanks.

In seconding the vote of thanks to Dr Fermor, Dr H. R. Mehra said —

I have great pleasure to second the vote of thanks proposed by Prof M. N Saha to Dr Fermor, who has come here from Calcutta to preside over the Annual Meeting and address us this evening. It is remarkable in the history of the Academy that we have for our president to-day an eminent scientist and a geologist of world-wide fame. Dr Fermor is the first president of the National Institute of Sciences of India and as such we cannot expect a better authority than him to grace our meeting and encourage us in our humble beginnings. We already owe much to him in leading a way to bring the scientists of the country together under the National Institute of Sciences, in the creation of which

he has taken an active part. His efforts to bring about harmony among the scientists, who at one time appeared to show a hopeless disagreement in the founding of the Institute are well known and we are glad to say that they have met with great success through his great personality and tact. Dr Fermor, we are sure, will always take a keen interest in our activities, as our Academy is a side branch of the central Institute of which he is the President. As far as Geology is concerned, it is more or less obvious that he will not find much in the Proceedings of the Academy, but we trust that his presence here today will direct the authorities to consider seriously the feasibility of opening a department for the teaching of this important science in our universities. It hink it is a high time that a start in this direction should be made.

It is a great pleasure to me to second once more the vote of thanks to Dr Fermor, who has kindly taken the trouble to come over here for the Annual Meeting.

### **AWARD OF THE EDUCATION MINISTER'S GOLD MEDAL**

The Education Minister's Gold Medal was awarded to Dr H R Mehra, Ph.D. of the Allahabad University, Allahabad for his paper entitled 'New Blood Flukes of the Family Spirorchidae Stunkard from Indian Fresh-water Tortoises' considered to be the best paper in Zoology and Medicine published in the Journal of the Academy of Sciences, U P



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